AIR AND HEALTH

RONALD C. MACFIE

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BY

RONALD CAMPBELL MACFIE

M.A., M.B.C.M.

AUTHOR OF "THE ROMANCE OF MEDICINE," "SCIENCE, MATTER, AND IMMORTALITY," ETC.

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CONTENTS

CHAPTER I

PAGE
GENERAL AND INTRODUCTORY. THE ATMOSPHERE . . 1

CHAPTER II

THE CHEMICAL COMPOSITION OF PURE AIR . . . 15

CHAPTER III

RESPIRATION 25

CHAPTER IV

AIR PRESSURE IN ITS RELATIONSHIP TO LIFE . . 52

CHAPTER V

TEMPERATURE OF THE AIR, AND HEALTH . . . 69

CHAPTER VI

HUMIDITY, AND THERMOLYSIS 76

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CHAPTER VII

PAGE
Humidity and Health 92

CHAPTER VIII

Air and Solar Radiation. Air and Electricity. Air and Radio-activity 102

CHAPTER IX

Impure Air 114

CHAPTER X

Polluted Air: *Smoke*, *Fog*, Gases in Mines, Ground Air, Sewer Air, Offensive Gases from Trades . 135

CHAPTER XI

Dust and Germs 161

CHAPTER XII

Ventilation 191

CHAPTER XIII

Open Windows, Draughts and "Colds" . . . 228

CHAPTER XIV

The Chest and Breathing 239

CHAPTER XV

PAGE
ARTIFICIAL ATMOSPHERES 262

CHAPTER XVI

CLIMATE 273

CHAPTER XVII

THE GASES OF THE ATMOSPHERE—THEIR DISCOVERY . . 293

CHAPTER XVIII

OPEN-AIR TREATMENT OF CONSUMPTION AND OPEN-AIR SCHOOLS 305

INDEX 329

AIR AND HEALTH

CHAPTER I

GENERAL AND INTRODUCTORY. THE ATMOSPHERE.

OVER the continents and oceans which constitute the geographical surface of the earth is heaped a vast volume of gases at least a hundred miles high. These gases, known collectively as the *air*, or *atmosphere*. consist of various substances which, under present conditions of temperature and pressure, retain a gaseous state. They not only lie on the surface, they also penetrate a certain distance into the soil, and reach to the bottom of the nethermost pit and of the deepest sea. They are odourless, tasteless, invisible, and we are hardly aware of them; as the Hon. Robert Boyle, one of the first to investigate their properties, remarks: "The generality of men are so accustomed to judge of things by their senses, that because the air is invisible they ascribe but little to it and think it but one remove from nothing." Yet unobtrusive though the atmosphere be, it is many removes from nothing, and has tremendous physical and mechanical potency, and even if we could live without it we should be deaf and dumb, on a frozen earth, under a starry black sky with a blue sun.

Let us now look briefly at some of the principal mechanical characters and properties of the atmosphere.

As a gas the atmosphere has special dynamical properties: it is elastic; it presses equally in all directions; it expands with heat and contracts with cold; its volume, at a constant temperature, is inversely proportional to its pressure. Regarded molecularly, it consists of various molecules darting about with tremendous velocity—the fastest about a mile a second, the slowest about 150 yards a second. "It has been reckoned that the number of impacts or collisions to which each molecule is subjected during each second in the tremendous recoil which takes place in the air amounts to something like 4,700,000,000. These molecules are exceedingly small, and Sir William Thomson (Lord Kelvin), Clerk Maxwell, and Van der Waals give their dimensions as being less than a fraction of one-millionth of a millimetre (a millimetre is $\frac{1}{25}$ inch)—one cubic centimetre of air at 0° and 760 millimetres pressure, containing in round numbers 21,000,000,000,000,000,000 of these molecules" (Henry de Varigny).

SPEED OF MOLECULES.

Molecules.	Average Molecular Velocity at 0° C. in cm. per second.
Carbon dioxide	33,259
Oxygen	39,155
Nitrogen	41,735
Water	56,522
Hydrogen	169,611

The pressure of the atmosphere at sea-level is 15 lbs. to the square inch, or about 2,000 lbs. to the square foot, or about 13,800 tons to the square mile, and the total weight of the atmosphere has been estimated by Mendeléef as 5,000 million million tons—a weight equivalent to a layer of mercury 30 inches deep, or a layer of water 34 feet deep, spread over the whole surface of the globe. A man of average size living at sea-level is exposed to a total pressure of about 34,000 lbs.—more than 15 tons. Such a pressure would crush animals and plants, if it were not for the fact that the pressure is exercised in all directions, upwards as well as downwards, from within as well as from without. As we ascend above sea-level, the total volume and weight of atmosphere overhead diminishes, and, since the molecules of the air are therefore less compressed, any given volume of air weighs less than on sea-level. At the height of 18,000 feet the pressure of the atmosphere is only half the pressure at sea-level. This decrease of pressure with increase of elevation can easily be demonstrated by means of a barometer, which will steadily fall as the height above sea-level increases. The following table gives approximately the height of the barometer at various altitudes:—

Altitude.	Height of Barometer.
0	30 inches.
910	29 „
1,850	28 „
2,820	27 „
3,820	26 „
4,850	25 „
5,910	24 „
7,010	23 „
8,150	22 „
9,330	21 „
10,550	20 „
13,170	18 „
16,000	16 „
18,000	15 „

This necessary relationship between altitude above sea-level and height of barometer was first surmised by Pascal. To prove his surmise his brother-in-law Perier carried a barometer to the top of the Puy de Dome—a mountain 3,500 feet high—and found that the column of mercury did actually fall 3 or 4 inches.

A difference of half an inch in the height of the mercury column equals a difference in air-pressure of about half a pound to the square inch, and corresponds roughly to an ascent of 900 feet.

During one of Coxwell's and Glaisher's balloon ascents the mercury column fell to 9¾ inches and possibly lower, indicating a height of at least 29,000 feet—say 6 or 7 miles. Even as the pressure decreases, and the column of barometric mercury falls when we ascend above sea-level, so does the pressure increase and the mercury rise when we descend below sea-level. In the valley of the Dead Sea, which lies below sea-level, the pressure is over 800 mm. At the bottom of a pit 40 or 50 miles deep the air would be as dense as mercury: we could actually cut it with a knife.

But increase and decrease in atmospheric pressure is conditioned by other circumstances besides height above sea-level; it is largely dependent on the temperature, humidity, and movement of the air.

Temperature.—When air is heated, it expands ·003665 of its volume for each degree Centigrade, and this expansion diminishes its tension, renders it lighter, and leads to a decrease in atmospheric pressure. Thus air heated to 40° C. at sea-level exerts just the same pressure as air at a temperature of 0° C. 1,090 metres above sea-level. The increase of the temperature of the air has decreased its pressure just as much as an ascent of 1,090 metres. On account of this relationship to heat, the atmospheric pressure is therefore usually lowest after the heat of the day, about 4 p.m., and highest after the cool of the night, about 10 a.m.

Humidity.—Under ordinary conditions air is not dry, but carries mixed with it a certain amount of water vapour. Now, the vapour of water is nearly 40 per cent. lighter than air, having a specific gravity of 0·623 compared with air as unity. Accordingly the more water vapour in the mixture, the lighter it is, and the less is the atmospheric pressure. Accordingly, also, a fall of the barometer showing reduced atmospheric pressure often indicates humid air and precedes rain; and a rising barometer often means dry air and dry weather.

The questions of pressure and humidity will be more fully discussed in later chapters.

The following instructive tables showing the relationship between weight and moisture and between weight and temperature are given by Dr. Huggard in his "Handbook of Climatic Treatment."

WEIGHT OF DRY AND OF MOIST AIR.

	Temperature.	Humidity.	Pressure in mm.			Weight in Grammes per Cubic Metre.		
			Dry Air.	Vapour.	Air and Vapour.	Dry Air.	Vapour.	Air and Vapour.
	° Centigrade.	Per Cent.						
Sea-level ...	0	0	760·00	0·00	760	1,293·2	0·00	1,293·2
		50	757·70	2·30	"	1,289·0	2·40	1,291·4
		75	756·55	3·45	"	1,287·1	3·66	1,290·8
		100	755·40	4·60	"	1,285·2	4·80	1,290·0
	15	0	760.00	0·00	760	1,225·5	0·00	1,225·5
		50	753·65	6·35	"	1,215·6	6·38	1,222·0
		100	747·30	12·70	"	1,205·4	12·76	1,218·2
Davos 1,550 metres above sea-level. ...	0	0	630·00	0·00	630	1,071·8	0·00	1,071·8
		50	627·70	2·30	"	1,067·2	2·40	1,069·6
		100	625·40	4·60	"	1,064·0	4·80	1,068·8
	15	0	630·00	0·00	630	1,016·0	0·00	1,016·0
		50	623·65	6·35	"	1,005·7	6·38	1,012·0
		100	617·30	12·70	"	995·5	12·76	1,008·2

RELATION BETWEEN PRESSURE AND TEMPERATURE OF THE AIR.

Temperature at Sea-level, 760 mm. Pressure.	Elevations.		Weight of Air in Grammes per Cubic Metre.	Height of a Column of Air representing 1 mm. Pressure.
	Height over Sea-level.	Pressure in mm. at 0° Centigrade.		
° Centigrade.	Metres.			
0	0	760·0	1,293·2	10·51
5	143	746·4	1,270·0	10·70
10	285	732·2	1,247·5	10·90
15	425	720·5	1,225·9	11·08
20	563	708·2	1,205·0	11·27
25	698	696·3	1,184·8	11·47
30	830	684·8	1,165·2	11·66
35	960	673·7	1,146·3	11·85
40	1,090	663·0	1,128·1	12·04

Movements.—The air has not only molecular motion: it also moves in large masses. The surface of the ocean of air, like the surface of the sea, has elevations and depressions, and the general body of the atmosphere, like the ocean, has currents and tides—draughts, and breezes, and gales, and hurricanes. These movements, involving an alteration in the disposition of the air, cause variations in its height and density, and corresponding variations in barometric pressure. When the air moves in large masses, its weight becomes at once apparent: it moves windmills: it wrecks armadas; it lays mighty forests low; and in the infancy of the world its power must have been still more prodigious. To the unmeteorological man the wind appears to blow "where it listeth"; but meteorological investigations have shown that it follows certain general laws, and is due to certain discoverable causes.

Putting aside the question of such small currents of air as are known as draughts, and local breezes due to local causes, we may say that the causes of the main atmospheric currents—the Trade Winds, the Anti-Trade Winds, and the

Monsoons—are the heat of the sun, and the rotation of the earth.

Being a homogeneous mixture under steady gravitational pressure, it might be supposed that the atmosphere would assume the shape of a regular spheroid, and would exhibit no great movement; but the atmosphere, though chemically homogeneous, is irregularly and unequally heated by the sun, and this irregular and unequal heating causes local variations in its density and in the amount of vapour it carries. The heated, moisture-laden, lighter air must rise, and the colder, drier air must rush in to take its place. The same thing happens in a heated room when the window is open above and below: the hot air expands and rises, and escapes from the top of the window, and the heavier cold air rushes in below to take its place.

When we study the heating of the atmosphere we notice at once that the belt of air within the Tropics receives much more heat than the air in the Polar regions. The following very interesting figures are given by Ferrel, showing the heat in various latitudes:—

Latitude.	January.	July.	Mean of Year.
	° Fahrenheit.	° Fahrenheit.	° Fahrenheit.
+ 80	− 25·4	+ 33·8	+ 4·1
70	− 15·7	+ 44·4	+ 14·4
60	− 1·6	+ 56·8	+ 29·1
50	+ 21·2	+ 65·5	+ 43·3
40	+ 40·1	+ 73·0	+ 56·5
30	+ 55·2	+ 79·9	+ 67·6
20	+ 71·1	+ 84·2	+ 77·5
10	+ 78·6	+ 83·1	+ 81·0
0	+ 81·1	+ 79·0	+ 80·1
10	+ 82·2	+ 75·2	+ 78·6
20	+ 79·9	+ 69·4	+ 74·7
30	+ 73·4	+ 60·1	+ 66·7
40	+ 63·7	+ 52·0	+ 57·9
50	+ 52·0	+ 43·5	+ 47·8
60	+ 58·5	+ 32·0	+ 35·2

The result of this thermal inequality is that the hotter air in the Tropics rises and divides into two currents which flow towards the North and South, while heavier colder air rushes along a lower level from the North and South to take the place of the lighter currents. The lower cold currents *from* the Poles are known as the *Trade Winds*, and the upper, warmer currents *to* the Poles as the *Anti-Trades.* The principle so far is plain, but there are points to be explained not so easy of explanation. The currents are found to run not due north and south: the upper currents to the Poles run North-west and South-west; while the lower currents from the Poles run North-east and South-east. Why is this?

The first to offer a satisfactory explanation of this apparent anomaly was George Hadley who, in a paper to the Royal Society in 1735, attributed the swerve of the great currents to the rotation of the earth. He pointed out that "the parallels are each of them bigger than the other as they approach to the Equator," and that, accordingly, since the air turns with the earth, the air over the Equator travels round Eastward in a greater circle and so with greater velocity than the air in the Polar regions.

When air rushes Northward from the Tropics and reaches more Northerly latitudes, it retains the Eastward velocity imparted to at its start, and therefore moves faster Eastward than the zones it passes over and appears as a North-west wind. Similarly the air rushing Southwards from the Tropics will appear as a South-west wind. These are the Trades.

When, on the other hand, air rushes towards the Equator from the Poles, it retains the low Eastward velocity imparted to it at these latitudes and, reaching latitudes where the earth is moving faster than itself, appears to come from the North-east or South-east. These are the Anti-Trades.

This theory held the field till 1859, when Professor Ferrel showed that it was mathematically incorrect: he pointed out that air going towards the Poles and from the Poles would not retain its initial gyratory velocity, but would in the first case increase and in the second case decrease in velocity.

The principle of this increase and decrease in rotational velocity is known as "the principle of equal areas" and can be easily illustrated by attaching a weight by a string to a stick and twirling it round the stick so that the string gradually winds up or unwinds. It will be noticed that as the string shortens the rotational speed increases, and as the string lengthens the rotational speed decreases. Now the wind which is rotating Eastward with the earth comes nearer the axis of rotation (the stick, so to speak) as it approaches the poles, and hence quickens in its rotatory movement; and it goes farther away from the axis of rotation as it approaches the Equator, and hence slows in its rotatory movement.

The general effect is the same as would follow from Hadley's theory, but rather exaggerated.

From a consideration of the motion involved in his principle Ferrel lays down the general law: "If a body moves in any direction upon the earth's surface, there is a deflecting force arising from the earth's rotation which deflects it to the right in the Northern Hemisphere but to the left in the Southern Hemisphere."

But there is still an anomaly to explain. The North-east and South-east Trade Winds blow only within latitudes of 30° North and South of the Equator. Why is this? According to the theories, as so far expounded, the wind of the lower atmosphere ought to blow from the North-east through all the latitudes from the Pole to the Equator; whereas the prevailing wind in the higher latitudes is really Westerly—North-west in the Northern Hemisphere and South-west in the Southern Hemisphere.

This is only a seeming anomaly, and is explained by the fact that the heated Anti-Trades descend as they travel Poleward, and, having high velocity, accelerate the Trades till at latitude 30 they give them a speed Eastward greater than the speed of the earth, and thus convert them into *seemingly* Westerly winds. In latitudes above 30 accordingly the atmosphere in its whole depth moves *quickly* Eastward with a velocity greater than the surface of the earth in these latitudes and causes Westerly winds.

If the Anti-Trades in their descent accelerate the Trades till they together outstrip the earth, it follows that at some point their speed must just equal the speed of the earth and hence cause no wind; and we find, accordingly, that about 30° or 35° North and South there are belts of calm known as the Calms of Cancer and Capricorn.

The situation, in general, as a result of the earth's motion, and of the heating of the atmosphere is that for 30° North and South of the Equator the earth goes faster than the atmosphere, and that in the higher latitudes the atmosphere goes faster than the earth. It is as though a dancing Dervish rotated faster than his belt but not so fast as his cap.

It may seem strange that the point of equilibrium between the currents of the air should be so near the Equator, but, as a matter of fact, the volume of the air of the belt is equal to the volumes North and South of it.

The highest strata of the hot Equatorial air going towards the Pole continue on up to the Poles, and by going high enough one can always find a West wind even when the Trades are blowing below. In fact, on nearly all high peaks a South-west wind can be found. "Very strong and prevailing Westerly winds," writes Ferrel, "have been observed on Mauna Loa in the Sandwich Islands, on the tops of Pike's Peak and of Mount Washington, in all the passes and on all the peaks of the Rocky Mountains and the Andes, on the Peak of Tenerife, the Himalayas of Asia, and at every elevated position in either hemisphere all around the globe, except at or near the Equator even in the Trade-Wind zones, where at the same time there is a wind of considerable strength from nearly the opposite direction." Leopold von Buch says, with regard to the Peak of Tenerife: "It is hard to find any account of an ascent of the Peak in which the strong West wind which has been met with on the summit has not been mentioned. Humboldt ascended the Peak on the 21st of June; when he reached the edge of the crater he could scarcely keep his feet, such was the violence of the West wind." The direction taken by the highest clouds and by volcanic dust ejected to great heights also demonstrates the Westerly direction of the highest strata of the atmosphere.

The Trades and Anti-Trades are, of course, constant currents; but periodic winds are much of the same nature, being all due to thermal irregularities.

The chief cause of periodic winds, such as daily sea breezes and Monsoons, is differences in the heating of air above land and above sea. When land and sea are exposed to the same sun heat the temperature of the land rises much higher than the temperature of the sea, and it gives off heat much more quickly to the air overlying it. If the same amount of sun heat falls upon an equal area of land and water it raises the temperature of the former four or five times as much as that of the latter. On the other hand, the sea holds its heat longer; and after the sun has set, or in winter, will be giving off heat to the air above it while the land is comparatively cold.

Thus in the daytime when the sun is shining the greater heat of the land causes the ascension of hot air over it, and cooler sea-breezes blow in landward. In the evening, on the other hand, the sea gives off more warmth than the land, and the air over it rising, cooler breezes blow seawards from the land. The breezes are just the same in principle as the draught up a chimney.

On a small scale, the same principle is seen at play in theatres, and churches, and cathedrals, and public buildings. The great mass of people crowded together heat the air above them and it ascends, and cool air rushes in from the aisles to take its place, hence the almost unavoidable draughts in such places.

The Monsoons.—The Monsoons are winds of the same nature on a large scale. They are due to the heating of the air above large tracts of country, such as deserts, and the consequent aspiration of cooler currents from the sea. The Indian Monsoons may be considered typical of this class of wind. In the Northern summer the land of India, protected from the cold North winds by the Himalayas, becomes so hot that the air above it becomes hotter even than the air at the Equator. Hence the South-east Trade Winds are drawn across the Equator even to India. The South-east wind, however, becomes so accelerated (on the principles we have already explained) in its passage Northwards that it becomes a South-west wind—the South-west Monsoon. The South-west summer Monsoon, therefore, is nothing more than the South-east Trade prolonged, accelerated, and diverted by the heat of India.

The North-east winter Monsoon is simply the reversed current (the breeze off the land) going South again with the Trade Wind, and it is again accelerated into a Westerly wind as it crosses the Equator and is drawn down to Australia by the heated land there. Both Monsoons become laden with moisture as they cross the Equator. A few other special winds may be mentioned.

Cyclones.—"A cyclone is a large disc of nearly horizontally moving air circulating spirally round a central area over which the barometric pressure varies from one-fifth to as much as 3 inches below that of its border." From Ferrel's law it follows that in whatever direction the wind starts it always deviates to the right, with the consequence that winds in the Northern Hemisphere blowing Northwards circulate from West to East and blowing Southward from East to West, while in the Southern Hemisphere these directions are reversed. All storms have a cyclonic character.

Tornadoes are rapidly whirling columns of air; they are caused by a bursting of the lower strata of the atmosphere through those above, much "as the vapour of boiling water, which is generally mostly at the bottom of the containing vessel, bursts up through the water above and comes to the surface." As the tornado column ascends it also rushes along with terrific force, and the damage it can do is almost incredible. In a tornado at Illinois June 4, 1877, "Lewis Gott saw the tornado strike his house, his point of observation being one square North. As he described it, the house appeared to go up bodily and plunge into the cloud. Only a very small portion of it was ever seen afterwards, to be recognised." And one could fill a volume with accounts of such sensational destruction.

Special winds specially exhilarating or depressing have received special names, *e.g.*, Sirocco, Föhn, Solano, Mistral, Chinook, but these cannot be discussed here.

Rate of Wind.—In the Southern Hemisphere, owing to the greater proportion of sea, there is less friction between the atmosphere and the surface, and the Westerly winds of the higher latitudes blow with more force. And as a rule there is more wind on sea than on land. External friction, however, is not a factor of great importance, for Helmholtz calculated that "if the atmosphere generally started moving over the earth with a certain average velocity, say of 20 miles an hour, it would take no less than 42,747 years to reduce this to 10 miles an hour by the action of friction with the ground."

Since the air becomes rarer as we ascend, its internal friction diminishes, and the velocity of winds—whether local winds from local causes, or the great wind-currents we have mentioned—increases. Clayton, in 1883–5, from observations of clouds, made the estimate that the average velocity of wind increases about 2 miles an hour for every 1,000 feet of ascent, and that in winter the winds in the upper air are twice as rapid as in summer. The cirrus cloud in winter travels 96 miles an hour. The average rate of surface wind on land varies from 6 to 12 miles an hour and diminishes as we go inland. The following are Scott's, and Sprung's and Köppen's estimates of the strength and rate of winds.

	Scott.	Sprung and Köppen.
0. Calm	3 miles per hour	2.23 miles per hour
1. Light Air	8 " " "	6·26 " " "
2. Light Breeze	13 " " "	9·1 " " "
3. Gentle Breeze	18 " " "	9·12 " " "
4. Moderate Breeze	23 " " "	15·2 " " "
5. Fresh Breeze	28 " " "	18·8 " " "
6. Strong Breeze	34 " " "	22·8 " " "
7. Moderate Gale	40 " " "	26·1 " " "
8. Fresh Gale	48 " " "	30·0 " " "
9. Strong Gale	56 " " "	34·2 " " "
10. Whole Gale	67 " " "	
11. Storm	75 " " "	
12. Hurricane	90 " " "	

Tornadoes may go hundreds of miles an hour.

CHAPTER II

THE CHEMICAL COMPOSITION OF PURE AIR

THE atmosphere is now known to contain the following gases in the following approximate proportions by volume, measured at 0° C. and at 760 mm. pressure.

	Volumes per cent.
Oxygen	20·94
Carbon dioxide	0·03
Nitrogen	78·09
Argon	0·94
Helium, krypton, neon, xenon	traces.
Hydrogen, hydrogen peroxide, ammonia	

Pure air, in addition, contains water vapour in varying amounts, nitric and nitrous acid, radio-active substances and emanations, and dust.

It must be understood that the gases of the atmosphere form a mixture, and are not chemically combined. The proofs of this are manifold. (1) The gases do not occur in atomic proportions; (2) on adding them together in atmospheric proportions there is no heat evolved; (3) the composition of air, within limits, is variable; (4) when water dissolves air it dissolves each gas according to its partial pressure and its own proper coefficient of solubility.

We shall now consider in greater detail the various gases of air.

Oxygen.—Oxygen is a colourless, odourless, tasteless gas which can be liquefied at a temperature of 140° C. under a pressure of 320 atmospheres. Free and in combination it is one of the most plentiful of gases: it forms nearly half the crust of the earth, and more than half the water on the earth and in the sky: it also forms more than a fifth of the atmosphere. It is the gas which causes combustion, and it is the gas which plays the most illustrious part in the chemical phenomena of life. Joining the living molecule it makes the compound more explosive, and the explosion is the chemical basis of the actions and processes of life. When the molecule explodes, the oxygen flies into the air again, wedded to carbon. Considering the number of chemical processes in which oxygen takes part, one might imagine that the amount of it in the atmosphere would vary from time to time; but, as a matter of fact, the amount varies very little: it averages about 21 per cent. by volume, and in open air is seldom much more or less.

Regnault, a famous French chemist, examined 195 specimens of air—100 specimens from Paris, and others from other parts of the world, and obtained the following results:—

				Oxygen per cent.		
100	specimens	from	Paris	20·913	to	20·999
9	,,	,,	Lyons and around	20·918	,,	20·966
30	,,	,,	Berlin	20·908	,,	20·998
10	,,	,,	Madrid	20·916	,,	20·982
23	,,	,,	Geneva and Switzerland ...	20·909	,,	20·993
15	,,	,,	Toulon and Mediterranean	20·912	,,	20·982
5	,,	,,	Atlantic Ocean	20·918	,,	20·965
1	,,	,,	Ecuador	—		20·960
2	,,	,,	Pinchincha, higher than Mont Blanc	20·949	,,	20·981
			Mean of above	20·949		20·988

Bunsen, a famous chemist, as the result of numerous estimates, found that oxygen in the air of Heidelberg varied between 20·924 and 20·840 per cent.

In the crowded and smoky parts of cities there is usually some deficiency of oxygen. Thus R. Angus Smith found that air taken from a smoky district in the middle of Manchester had an average oxygen percentage of only 20·677. Indoors and in mines there may be a somewhat larger decrease in the percentage of oxygen. We shall return to this subject when dealing specially with the air of habitations and towns.

It might be thought that since oxygen plays such an important part in the phenomena of life that more oxygen would mean more vitality, and less oxygen less vitality. This is not so. Not only are such slight differences as we have noted in the percentage of oxygen of no importance *per se*, but much larger variations in amount may occur without any obvious physiological effect. The percentage of oxygen present in the natural atmosphere is probably the percentage most favourable to life; but under normal conditions it may drop to 13 per cent., or may rise to 50 per cent., or even higher, without any very apparent alteration in the vital functions. Vital chemistry is very adaptable in this respect; and a little quicker or deeper breathing, a little quicker circulation, may compensate for lack of oxygen even when the amount in the air is less than the tissues under normal physiological conditions require. A lowered percentage of oxygen in the air, however, though not harmful *per se* is usually an indication of impurities which may be detrimental to the health. Under certain circumstances, which will be explained later, inhalations of pure oxygen may assist the tissues to obtain sufficient oxygen which otherwise they would fail to obtain.

In too large and concentrated doses, oxygen is a poison and will cause convulsions, inflammation of the lungs, and even death.

Ozone.—Ordinary molecules of oxygen consist of two atoms; but, under certain circumstances, three atoms are condensed into the molecule. Such tri-atomic oxygen, known as *ozone*, is found in small amounts in pure air and has great chemical activity, since the third atom is loosely combined, and ready to leap forth and oxidise any oxidisable substance. Unlike ordinary oxygen, ozone has a flavour (which has been likened to the flavour of a lobster) and a very powerful odour. So powerful is the odour that it can be detected by smell, even when present in such a minute proportion as 1 volume in 2,500,000.

Ozone is rarely found in natural air in greater proportions than 1 part in 10,000, but it is so potent chemically that even so small a quantity is of importance.

It can be artificially produced in various ways, *e.g.*, by passing an electrical current through oxygen or air, by the electrolysis of acidulated water, by the action of strong sulphuric acid upon potassium permanganate, by half immersing in tepid water a stick of clean phosphorus, by spraying water through air, by the oxidation of essential oils, chloroform, sulphuric ether, &c.

Atmospheric ozone is formed by the electricity of the air (after electrical storms it can often be smelt), by the oxidation of phosphorescent substances, and perhaps by the respiration of plants.

The "man in the street" has a great respect for ozone: he goes to Brighton or Margate or the moors to have a whiff of it, and ascribes to it marvellous health-giving properties. The direct effect of ozone on the health, however, must be very small, for it is caught by organic matter in the nostrils and large air-tubes, and never can come into direct contact with the blood. On the other hand, it does purify the air of organic matter, and perhaps of floating germs, and if some of it is left over unemployed, it indicates that the air is free from impurities. In rooms and enclosed spaces and streets it cannot be found, while it is specially plentiful on the tops of mountains and by the sea, and in dry air after a fall of snow. The percentage of ozone in air at the Grands Mulets on Mont Blanc was found to be four times as great as in Paris. It is more plentiful by night than by day, and it is decomposed by heat. In large amounts such as 1 volume in 250 it is fatal to life, and even such amounts as naturally occur in the air may irritate the respiratory mucous membrane and cause or aggravate nasal catarrh, or bronchitis, or asthma.

Carbon Dioxide.—Carbon dioxide is a colourless, odourless gas which occurs in the atmosphere in very small amounts and is yet of great biological and physiological significance. It is produced by the processes of respiration and combustion, and is also ejected by volcanoes, and by effervescent mineral springs. At the ordinary temperature and pressure water dissolves about its own volume of the gas, and in solution the gas exercises a very corrosive effect on the rocks of the crust of the earth. The carbon dioxide in the air is the source from which green plants, with the assistance of sunlight, obtain their carbon, and is thus indirectly the source of the carbon in the bodies of animals. On the one hand there is a constant subtraction of the gas from the air by rocks and plants, and on the other hand a constant addition of it to the air by combustion, respiration, and volcanic action; and subtraction and addition probably about balance, so that the average percentage of the air continues steady. Any considerable alteration in its percentage either up or down would alter the climate of the earth and might cause the death of all living organisms.

"If it (the carbon dioxide) were to be destroyed," writes

Varigny, "if air were to contain no more of it, all plants on the surface of the earth would die within a short period—some weeks at most. After this, as a matter of course, herbivorous animals would die, and this would not require more than a month. Carnivorous animals would hold out a little longer, as the stronger would feed upon the weak, but after a few weeks they also would go in turn and only a few miserable, half-starved specimens of mankind would be seen feebly struggling from one rotting carcass to another, amidst as barren scenery as can be observed by looking at the moon through a telescope, and they too, would have to die soon after, notwithstanding cannibalism or such other extreme methods as dire necessity might suggest. In a few months all nature would be dead."

So much do we depend on the minute quantity of carbon dioxide in the air.

It is customary in text-books to state the percentage of carbon dioxide in the air as ·04; but if we are to believe recent estimates, ·03 would be a more accurate figure. This percentage shows surprisingly few variations—unless in artificially vitiated air. Thus—to select a few examples—Robert Angus Smith found the following percentages:—

Perth	·0341
Elgin	·0347
Foot of Ben Nevis	·0346
Top of Ben Nevis	·0327
Foot of Ben Ledi	·0335
Top of Ben Ledi	·0327

Müntz and Aubin found:—

Plain of Vincennes	·0284
Pic du Midi	·0286
Pyrenean Valleys	·0281
Farm of Agricultural Institute	·0298

Florida	·0292
Mexico	·0273
Chubut (Patagonia)	·0295
Santa Cruz...	·0266
Chili...	·0269
Haiti	·0278
Cape Horn...	·0256
Mean of Northern Atmosphere...	·0282
Mean of Southern Atmosphere...	·0272

The results of examinations by J. S. Haldane and E. S. Haldane are given in the following table:—

Time of Year.	Time of Day.	No. of Analyses.	Carbon Dioxide per 10,000.		Average.	
			Maximum.	Minimum.		
April 1 to September 30	Day ...	29	3·11	2·58	2·88	2·98
	Night	22	3·55	2·82	3·08	
December to January	Day ...	6	3·12	2·93	2·99	3·00
	Night	5	3·06	2·94	3·01	

Schultze, as the result of over a thousand examinations at Rostock, found a mean percentage of ·0292. Thorpe in 77 investigations of ocean air found a mean percentage of ·03. Letts and Blake found in Dublin a mean average of ·029. Brown and Escombe, as the result of 91 examinations of air at Kew, found mean percentage of carbon dioxide to be ·029.

Making allowance for the imperfections of Dr. Angus Smith's method we find a remarkable uniformity in the percentage, and we notice that the mean percentage is rather under than over ·03.

As a rule, inland air is richer in carbon dioxide than air near the sea or near surfaces of water, and night air on land is rather richer in the gas than day air. To show the latter variation, the following table is given by Letts and Blake ("Scientific Proceedings," Royal Dublin Society):—

Date of Observation.	Observer.	Locality.	Number of Observations.		Carbon Dioxide in 10,000 Vols. of Air (Mean Result).		Excess. Absolute.		Excess. Percentage.	
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.
1827–1830	De Saussure ...	Geneva......	52	52	3·98	4·32		0·34		8
1840–1841	Boussingault ...	Paris.........	—	48	3·90	4·20		0·30		8
1875	Truchot	Clermont Ferrand...	—	—	3·53	4·03		0·50		14
"	Wolffhügel......	Munich ...	35	35	3·93	4·04		0·11		3
1879	v. Fodor	Buda Pesth	—	—	4·18	4·26		0·08		2
"	Armstrong	Grasmere...	53	62	2·96	3·30		0·34		11
1882	Müntz & Aubin	Florida ...	8	6	2·90	2·95		0·05		2
"	"	Martinique	4	6	2·73	2·85		0·12		4
"	"	Mexico......	4	2	2·66	2·86		0·20		7
"	"	Chili	8	2	2·66	2·82		0·16		6
"	"	Chubut......	2	2	2·79	3·12		0·33		12
"	"	Santa Cruz	14	6	2·66	2·67		0·01		37
1882–1883	"	Haiti.........	10	6	2·70	2·92		0·22		8
"	" (Hyades).........	Cape Horn	—	—	2·563	2·556	0·007	—		—
1885	Wollny	Munich ...	—	—	3·30	4·25		0·95		29

The reason of the greater richness in carbon dioxide of night air is doubtful; but the excess of carbon dioxide is probably due, as suggested by v. Fodor and Wollny, to the fact that the ground air is richer in carbon dioxide, and the ground air at night being warmer than the atmosphere, ascends. It may, of course, also be due in some measure to the fact that at night vegetation no longer absorbs carbon dioxide.

It might be thought that vegetation, by absorbing carbon dioxide and expiring oxygen, would considerably diminish the percentage of carbon dioxide in the air; but experiments so far show very slight diminution, probably owing to the fact that diffusion is so rapid and continual. If vegetation effected much change in the carbon dioxide percentage of the air, we should find that air in winter is much richer in carbon dioxide than air in summer; but this seems not to be the case, and if there be any difference it is very small.

The air of towns, even in clean, well-ventilated streets, has a slightly larger percentage of carbon dioxide than country air. Thus Boussingault and Levy found ·0319 per cent. of carbon dioxide in Paris air, and only ·0299 per cent. in Andilly, a small village 12 miles away.

It was formerly believed that with increasing altitude there was decrease in proportion of carbon dioxide in the atmosphere, but recent investigations have disproved this belief. Thus air collected at great heights by balloons had just the same percentage as air at sea-level. A sample of air obtained by a balloon at the height of 15,500 metres was found by Muntz to contain ·033 per cent. of carbon dioxide.

Rain seems to decrease, and snow, fogs, and mists to increase the percentage of carbon dioxide in the air. F. Schulze gives the following figures with regard to snow :—

Before Snow-fall.	After Fall of Snow.	
2·56	50 grm. snow	2·71
2·69	400 ” ”	2·81
2·80	250 and 750 ” ,,	3·37
2·96	240 ” ”	3·15
2·77	250 ” ”	3·04
2·75	500 ” ”	3·03

Wind has a tendency to decrease the percentage of carbon dioxide by diluting any excess with pure air. Low barometric pressure, on the other hand, tends to increase the carbon dioxide, favouring the escape of ground air.

The normal variations in the carbon dioxide of natural air in the open are too small to be of therapeutical importance, and it is only when stagnant or enclosed air is polluted by combustion and respiration that we find variations likely to affect the health.

Nitrogen.—Nitrogen which forms four-fifths of the atmosphere by volume is an odourless, colourless, tasteless gas. It has little chemical activity, and so far as respiration is concerned, it acts simply as a diluent of oxygen and carbon dioxide, and is breathed in and breathed out again quite unchanged. It is, however, the original source of the nitrates in the soil from which plants obtain their nitrogenous food, and some algæ and bacteria have the power of assimilating it directly from the atmosphere. Moreover, it must play a considerable part in the sifting of solar radiation.

Helium, Argon, Krypton, Xenon, and Neon.—These gases occur in very small proportions in the atmosphere, and seem to have no physiological significance.

Ammonia.—Ammonia is a product of organic decay, and is therefore always present in the air in small amounts—a few millionths. It has no physiological significance, but being brought down to the soil by rain it exercises a fertilising influence. It has been calculated that each 2 acres of ground in France receive annually through the rain about 25 or 30 lbs. of ammonia.

Nitric and Nitrous Acids.—These acids are formed in the air by atmospheric electricity, and occur in quantities even smaller than those of ammonia. Like ammonia, they have no physiological significance, and, like ammonia, they fertilise the soil.

Hydrogen, Sulphuretted Hydrogen, Carburetted Hydrogen, and Marsh Gas.—All these gases are also found in pure air, but in such insignificant quantities as to be negligible.

In air near the sea there is a considerable quantity of sea-salt. All natural air also contains radio-active emanations and substances, dust and water vapour; but these will be separately considered.

CHAPTER III

RESPIRATION

ALL living organisms may be considered as condensed gases, and the manifestations of life—motion, assimilation, reproduction — require, in almost every instance, a continual interchange of molecules between these condensed gases and the free molecules of certain gases of the atmosphere. When this interchange ceases, the manifestations of life cannot long persist. Men and flowers and most microbes are alike subject to this law: they require air; they require to breathe. Even in dead organisms and in the inorganic world an interchange or acquisition of gaseous molecules takes place: the sea gives and takes gases; the iron rusts; the fire burns; the rocks are "weathered." The interchange of gases, however, associated with the manifestations of life is distinctive; it is always duplex, and always consists—so far, at least, as respiration is concerned — of the acquisition of oxygen, followed by the surrender of a volume of carbon dioxide about equal to the volume of the oxygen inspired. On this principle, all animals and probably all the higher plants breathe, and the process is called the process of respiration. In addition to this respiration, plants have other traffic with the atmosphere which is usually considered assimilative and not respiratory; they take carbonic acid from the air, break it up, with the assistance of sunlight, into carbon and oxygen, and keep the carbon and restore oxygen to the atmosphere. The enormous coal deposits consist of carbon thus extracted from the air. The process, though considered assimilative, is essentially respiratory; it consists of a chemical reaction between the cells of the plant and the atmospheric gas, and the mere fact that the gas is partially retained does not alter the essentially respiratory character of the processes.

In the lowest unicellular organisms respiration is mainly a chemical process; mere molecular contiguity suffices to induce combination, and almost the only physical conditions requisite are a certain temperature and a certain air-pressure. A small round cell can lie in a stagnant atmosphere, and breathe sufficiently by means of its general surface to keep alive. The larger the cell, however, the smaller its surface in proportion to its bulk, and the larger cells therefore usually have arms and processes to increase their respiratory (and assimilative) surface, or are able to move about, and thus get more air (and food). When they reach a certain size, too, they usually divide to increase their superficies.

In the case of multicellular organisms, whose surfaces bear a small ratio to their bulk, mechanical means become necessary to provide sufficient gas. In the case of the higher plants, the motion of the wind and the motion of the leaves give a constant fresh supply of air, and it may be noticed that the spring winds occur just at the time when the growth of plants is most vigorous. It may be noticed, too, that as a rule the smaller the leaves the more do they move. Compare, for instance, the movement of the leaves of an aspen or birch with the movement of the leaves of a cabbage or horse-chestnut.

In the case of fishes, again, the movement of the water across their specialised respiratory surfaces known as *gills* serves to bring a constant stream of oxygen to their tissues and to carry away the carbon dioxide discharged, and the blood which flows through their tissues serves a similar purpose. There is a proverb which says, "Rough water makes firm fishes," and no doubt the fishes are firm because the rough water supplies them with plenty of oxygen.

In the case of the smaller water insects the expedients adopted for procuring oxygen are most remarkable. The water-beetle, for instance, has a sort of air-tank under its hard, polished wings, and every time it comes to the surface it fills the tank with air. The water-spider, again, is covered with hairs, and every time it dives it carries down minute bubbles of air attached to the hairs. Not only so, but it actually brings down big bubbles of air between its body and its folded legs, and stores them in its cocoon for the use of its young.

The larger land animals have the respiratory surface at which gaseous interchange can take place immensely extended by its plication into the pulmonary air-sacs. Further, the supply of fresh air is increased by means of a special bellows-like muscular apparatus, and the gases are carried to and fro between the respiratory surface and the cells of the body by means of currents of blood. Man's skin, and even his alimentary canal, can take up oxygen and give off carbon dioxide to some extent; but the quantity so exchanged is so small as to be negligible, and practically the whole respiratory exchange between the atmosphere and the human body occurs at the extensive mucous membrane lining the air-cells, the so-called *alveoli* of the lungs.

We will now briefly describe the structural features and mechanism of the breathing apparatus in man.

It consists of the mouth, nose, and larynx, the trachea, and lungs, and the whole vascular system. The trachea extends from the larynx to the chest, and within the chest bifurcates into smaller and smaller branches till they reach almost microscopic dimensions. When they have reached almost microscopic dimensions they expand somewhat into little elongated sacs known as *infundibula*, with numerous little dimples or indentations all over their interior. The deep dimples are the *air-cells*, or *alveoli*, and looked at from the outside the infundibula with their dimples look something like bunches of grapes in bas-relief. The infundibula are covered all over on the outside with a network of very fine blood-vessels (capillaries), and the infundibula and blood-vessels are all bound together by a fine, stringy, elastic substance known as *connective tissue*, into the lobes of the lungs.

The lungs are thus porous and elastic, and contain a large quantity of blood ; and the pouching of the infundibula affords a very large mucous surface which is in contact with the inspired air. It has been calculated by Aeby that there are over four million air-cells, and that the total surface is about 50 square metres at the end of a deep expiration and about 130 square metres (since of course the air-cells are stretched) at the end of a deep inspiration. Zuntz, again, calculates that these are over seven hundred million air-cells with a total surface of about 90 square metres, and Lindenau estimates a surface of 2,642 square feet. Whichever estimate we accept there is evidently a large superficies.

The trachea is strengthened by rings of cartilage, so that it always remains open, and resists a considerable amount of pressure; but the branches into which it divides have more and more delicate walls, and when we come to the infundibula they are reduced to mere films.

All the air-tubes, except the finest final divisions, are lined with a sort of mosaic of cells set side by side like a number of closely packed jars, or cartridges, and the upper free surfaces which form the lining of the tubes have fine, hair-like prolongations known as *cilia* which are in constant motion and move in such a way as gradually to work mucus and any foreign particles upwards towards the throat. The surface-lining of the tubes is very smooth and glistening and is lubricated by a secretion like raw white of egg (the *mucus*) which is secreted by means of mucous glands.

The lungs, thus composed of air-tubes, air-cells, blood-vessels, and connective-tissue, occupy the cavity of the thorax, lying one on each side, with the heart between them, and heart and lungs quite fill the chest cavity.

The walls of the chest cavity are formed by the breast-bone and ribs, with the intercostal and other muscles, and its floor is formed by the diaphragm—a layer of muscle and fibrous tissue, which separates it from the abdominal cavity.

As is well known, the chest expands and contracts with the breathing; and the usual idea of the unphysiological is that the drawn-in breath fills the lungs and causes expansion of the chest, whereas the physiological fact is that the inspiration is the effect and not the cause of the expansion. In slang the chest is sometimes spoken of as the *bellows*, and the term is quite appropriate, for even as air enters at the nozzle of a bellows when a bellows is expanded, so it rushes through the throat into the lungs when the chest is expanded.

The chest cavity is expanded by means of special muscles—chiefly the rib muscles and the diaphragm, which usually act automatically under reflex nerve control and chemical stimulation, but which are also under the control of the will. The muscles of the abdomen also participate in the action of breathing, and in forced breathing a great number of auxiliary muscles may be brought into play.

As we have just said, the entrance of the air into the lungs is the same in principle as the entrance of the air into a bellows: it is a process of aspiration. The enlargement of the chest cavity rarefies the air within it, and the air rushes down the trachea to equalise pressure.

The expiration of air is due chiefly to the elasticity and weight of the chest walls and is ordinarily a quite automatic function; but muscular action also plays a part and may be voluntarily exerted.

All the reflex muscular mechanism of breathing is regulated by a nerve centre situated in the bulbous enlargement at the top of the spinal cord, known as the *spinal bulb*, or *medulla oblongata*. This nerve centre controls not only the respiratory muscles of the ribs and abdomen, but also the small muscles in the walls of the air-tubes.

The impulses sent out from the nerve centre are the outcome of the rhythmic vital chemistry of the nerve cells, but the rate and force of the impulses are regulated by other afferent nerve impulses which reach the centre from the lungs and from numerous other areas, and by the character of the blood supply. Thus a violent emotion may take the breath away, a little snuff in the nostrils or a little sunlight in the eyes may cause a sneeze, a little excess of carbon dioxide in the blood may quicken the respiration. We shall see later how beautifully the mechanism is regulated by these reflexes so that the air supply varies with the requirements of the system.

The chief nerves running between the respiratory centre and the respiratory machinery are the intercostal nerves which supply the ribs, the vagus nerve which goes to the larynx, lungs, and heart, and the phrenic nerve which goes to the diaphragm.

The net result of the nerve impulses is to cause regular and alternate expansion and contraction of the chest cavity, whereby air is alternately inspired and expired at the rate of 15 or 16 times a minute.

The volume of air inspired and expired depends on the rate and extent of the respiratory movement, but in an adult man of average size and vigour about 500 cubic centimetres of air are inspired and expired during quiet breathing. This volume of air is known as the *tidal air*, and, since the total volume of air in the lungs is about 3,500 c.c., it is evident that in normal breathing a large amount of air—3,000 c.c.—remains in the lungs at the end of expiration. The air which remains behind is known as *stationary air*. By *forced* expiration about half of the stationary air, *i.e.*, 1,500 c.c. can be expired, and this portion of the stationary air is known as the *supplemental* or *reserve* air, while the final 1,500 c.c. which no effort can expel is known as the *residual* air. The total 3,500 c.c. of air in the chest, then, at the end of ordinary inspiration is made up as follows:—

Tidal air	... ...	500 c.c.
Stationary air	Supplemental or Reserve	1,500 c.c.
	Residual	1,500 c.c.
	Total ...	3,500 c.c.

When, however, inspiration is forced, another 1,500 c.c. of air known as *complemental* air can be inspired, making altogether 5,000 c.c. The total amount of air (complemental, tidal, supplemental) which can be expired after forced inspiration is known as the "respiratory capacity" or "vital capacity," or "extreme differential capacity," and the amount varies considerably according to height, weight, vigour, age, &c.

Now, what is the vital meaning of these two spongy organs, and this ebb and flow of air?

For centuries the meaning was not understood; for centuries the theories of respiration were erroneous and fantastic. Aristotle, for instance, taught that the windpipe carried air to the heart to keep it cool. "The hotter the animal," he says, "the more vigorously must it breathe in order the more effectually to subdue the heat." On this principle he argued that fishes died out of water because their hearts were cooled too much, and that animals died under water because their hearts were not cooled sufficiently. Later, Galen taught that the air went to the heart, and in the heart was concocted into vital spirits; and though in the middle of the sixteenth century Winter, Servetus, Columbus, and Cesalpinus discovered the circulation of blood through the lungs, the Galenic doctrine of the concoction of spirits still persisted.

Not, indeed, till the time of Mayou, 1668, was the true meaning of respiration suspected, and not till the eighteenth century could the principle of the process be said to be really understood.

The manifestations of life require, as we have said, an interchange of gases between the living cells of the body and the air, and the whole mechanism of respiration is designed to facilitate this interchange. The respiratory movements bring oxygen to the blood for transport to the tissues, and carry away the carbon dioxide brought by the blood from their tissues. The whole structure of the lung, again, is of such a nature as to give a large surface of contact (50 or 90 square metres we have seen) between the blood and the atmosphere, and allow free and extensive interchange.

Respiration is entirely a matter of the loading and unloading and transport of gases, and the air-cells may be regarded as the docks where the gases are loaded and unloaded.

The tissues require oxygen, and the blood flowing to the tissues from the lungs collects oxygen at the air-cells as fast as the respiratory movements inspire air. The tissues again require to get rid of the carbon dioxide they form, and the venous blood, as it passes from the tissues over the air-cells, discharges carbon dioxide into the air there, whence it is expired with the expired air. Briefly, the inspired air gives oxygen to the venous blood (over the air-cells) and the expired air takes carbon dioxide from the venous blood (over the air-cells), thus converting it into arterial blood, and changing it from a dark red into a bright red colour.

The gaseous changes in the air and blood are shown in a general way in the following table:—

	Volume per cent. (approximate) at 0° C. and 760 mm.		
	Oxygen.	Nitrogen.	Carbon Dioxide.
Inspired Air	21	78	·03
Expired Air	16	78	4·3
Blood reaching the lung	8 to 12	1·2	46
Blood after exposure to air in the lung ...	20	1·2	40

In the alveoli of the lungs the carbon dioxide is kept at a percentage of 5 or 6 per cent.

If the breath be held, the venous blood in the lungs continues to absorb oxygen from the air and to give up carbon dioxide to the air. By holding the breath for 100 seconds the percentage of carbon dioxide in the expired air may be almost doubled, and the percentage of carbon dioxide in the blood going to the tissues is also raised.

On what principle does the respiratory interchange of gases take place?

In the first place, why should there be gases in the blood at all? The presence of gases in the blood is in accordance with the general law that if gas is in contact with a liquid a certain volume of the gas becomes dissolved in the liquid. If there be no chemical affinity between the fluid and the gas, the amount of the gas dissolved at any given temperature varies with the pressure. If the pressure be doubled, the amount of gas in solution is doubled; and if it be halved the amount of gas is halved. We see every day in aërated waters how gases, in solution under a certain pressure, escape from solution as soon as the pressure is reduced.

But the absolute amount of a gas in solution at any given temperature, while varying with the pressure, also varies with the nature of the gas (for gases have varying solubilities) and on the nature of the fluid (for different fluids absorb different amounts of the same gas). Further, any alteration of temperature alters the solubility of any gas in any fluid.

The percentage volume of a gas reduced to 0° and 760 mm. which any volume of fluid will absorb at a pressure of 760 mm. (*i.e.*, atmospheric pressure) is known as the coefficient of absorption of the gas for the fluid. Thus the following table (from Bohr) gives the coefficient of absorption of various gases for water at varying temperatures:—

Temperature.	Oxygen.	Carbon Dioxide.	Carbon Monoxide.	Nitrogen.
0	0·0489	1·713	0·0354	0·0239
10	0·0380	1·194	0·0282	0·0196
20	0·0310	0·878	0·0232	0·0164
30	0·0262	0·665	0·0200	0·0138
40	0·0231	0·530	0·0178	0·0118

Blood plasma and blood have their own coefficients for gases, as the following table will show:—

	Oxygen.		Nitrogen.		Carbon Dioxide.	
	15°.	38°.	15°.	38°.	15°.	38°.
Blood plasma ...	0·033	0·023	0·017	0·012	0·994	0·541
Blood..............	0·031	0·022	0·016	0·011	0·937	0·511
Blood corpuscles	0·025	0·019	0·014	0·010	0·825	0·450

It may be well at this point to say a word on the pressure of the gases in a *mixture* of gases. If we distend an elastic bag with salt, the grains of salt will be under a certain pressure, and if we mix with the salt an equal quantity of sugar the grains of salt will be under double the pressure to which they were in the first instance subjected. A mixture of gases, however, behaves otherwise. If we take, say, a pint measure and fill it with nitrogen gas at atmospheric pressure the molecules of nitrogen will be under a certain pressure, *i.e.*, 15 lbs. to the square inch; and if we take another pint measure and fill it with oxygen at, say, half atmospheric pressure, the molecules of oxygen will be under a certain pressure, *i.e.*, 7½ lbs. to the square inch. If we add the oxygen to the nitrogen we will find that it will require a pressure of 22½ lbs. to the square inch to keep them in the pint measure, and yet, strangely enough, the original nitrogen and oxygen will not be the least more pressed. Each of them acts as if it alone were present in the pint measure: the nitrogen is still subjected to a pressure of one atmosphere, and the oxygen is still subjected to a pressure of half an atmosphere. Each presses against the wall surrounding it with a certain pressure, but neither interferes with the other at all.

Now the atmosphere is a mixture of gases which at sea-level (dry and at a temperature of 0° C.) is under a pressure of 760 mm. of mercury, *i.e.*, under a pressure of 16 lbs. to the square inch. But the gases of the atmosphere are not under that pressure individually; they each are under a pressure proportionate to their proportionate volume in the mixture. As we have seen, the proportional volume of nitrogen in air is approximately 21 per cent., of nitrogen 79 per cent., of carbon dioxide ·03 per cent. Therefore oxygen is under a pressure of 21 per cent. of the total pressure (760 mm.) $\frac{21}{100}$ of $760 = 159{\cdot}6$, and nitrogen is under a pressure of 79 per cent. of the total pressure $\frac{79}{100}$ of $760 = 600{\cdot}4$, and carbon dioxide is under a pressure of ·03 per cent. of the total pressure $\frac{{\cdot}03}{100}$ of $760 = {\cdot}228$.

As corollaries of this it is evident that by adding more oxygen and nitrogen or carbon dioxide to the air we increase only the pressure of the gas added, that we can get the same total pressure with various proportions of the same gases, and that the pressure of oxygen or carbon dioxide may be doubled without great increase in the total atmospheric pressure.

Coming back, then, to the question of the respiratory exchange of gases, we see that interchange between the gases of air and the blood must take place unless the pressure in each case is the same. If the pressure of any gas in the atmosphere be greater than the pressure of the same gas in the blood, then the gas will pass into the blood, even as carbonic acid gas under pressure passes into soda-water during the process of filling. Again, if the pressure of any gas in the blood be greater than the pressure of the same gas in the air, then the gas will pass from the blood into the air, even as the carbonic acid escapes from the aërated water when the cork is drawn.

The pressure of the carbon dioxide in the venous blood is greater than the pressure of carbon dioxide in the alveolar air, and therefore it passes from the blood into the alveolar air, and thence by a simple process of diffusion mixes with the general air in the lungs. Again, the pressure of oxygen in the alveolar air is greater than the pressure of the oxygen in the venous blood of the lungs, and therefore the oxygen passes from the alveolar air into the venous blood, and in the blood is carried to the tissues.

The principle so far is quite plain; but this is not all. When we shake up blood in air we find that it takes up a much larger volume of oxygen than we should expect under the laws that regulate gaseous solution under pressure, and it was discovered by Fernet that the excessive acquisition of oxygen is due to the fact that the oxygen not only goes into solution in the blood, but also enters into chemical combination with the red colouring matter of the blood. The plasma (*i.e.*, the fluid part of the blood minus the blood-cells) *dissolves* at ordinary temperature and pressure about ·65 volumes of oxygen per cent., whereas blood containing red corpuscles may absorb no less than 20 volumes of oxygen per cent.

The fact is of the greatest importance, for the red blood-cells are shown to be carriers of oxygen and to give the blood an oxidising capacity far greater than it would otherwise possess. The oxygen merely in solution does not suffice for life. Were the blood deprived of all its red blood-cells, a man would die of lack of oxygen just as certainly as if one strangled him ; and it is a well-known fact that those who are anæmic—who have too few blood-cells and too little hæmoglobin—are very short of breath. An anæmic girl cannot climb a few steps without losing her breath. In cases of poisoning by carbon monoxide again, the carbon monoxide enters into combination with the hæmoglobin and ousts the oxygen, and the victim of the poisoning dies from lack of oxygen even though there may be abundance in the air.

The acquisition of oxygen by the blood is thus a double process. In the first place, oxygen passes into solution in the blood because the pressure of oxygen in the alveolar air is greater than the pressure in the blood, and in the second place, as the oxygen enters into solution it is greedily seized by the red blood-cells.

As fast as the oxygen enters the lungs, it is carried away by the red blood-cells to the tissues and taken up there; and as fast as carbon dioxide is formed in the tissues it is carried by the blood to the lungs, and then carried away in the expired air.

It must be noticed, however, that the air in the alveoli is never directly changed by the movements of respiration—it is *residual;* and that the fresh oxygen inspired can reach the blood only by diffusing from the tidal into the residual air. Likewise the carbon dioxide discharged from the blood into the residual alveolar air is not directly expired but must first diffuse into the tidal air.

Respiration is thus a complex function combining processes of inspiration, expiration, diffusion, gaseous solution, chemical combination, and circulation. The oxygen inspired in the tidal air diffuses through the residual air to the alveolar air, thence passes into the blood partly chemically combined and partly in solution, and so is carried in the circulation to the tissues. The carbon dioxide formed by the cells in the body is carried by the blood to the capillary networks of the air-cells and passes out of solution into the alveolar air, whence it diffuses into the tidal air, and in the tidal air is discharged at expiration.

Let us now examine a little more in detail the respiratory exchange between air and lungs, and lungs and tissue.

As we have seen, the air before inspiration contains 21 volumes per cent. of oxygen and ·03 per cent. of carbon dioxide and after inspiration 16 per cent. of oxygen and 4·3 per cent. of carbon dioxide, and the venous blood, which contains 8 or 12 volumes per cent. of oxygen and 46 volumes per cent. of carbon dioxide, leaves the lungs containing 20 volumes per cent. of oxygen and 40 of carbon dioxide. These are such results as we might theoretically expect.

Now it must be noticed that the air expired is the tidal air expired from the upper portions of the lungs, and must therefore be much purer than the stagnant air remaining in the lungs—certainly considerably purer than the air away down in the air-cells where the exchange is actually taking place, and that therefore the exchange between air and blood is between rather impure air and blood.

We have said that most of the oxygen taken up by the blood is taken up by the chemical affinities of the red colouring matter of the blood and that the amount in solution according to the law of pressure is comparatively small; but it must be remembered that even chemical affinity is influenced by pressure, and that with increase of pressure more oxygen is taken up, and that with decrease of pressure less oxygen is taken up. When the oxygen pressure is reduced to below half the pressure of oxygen in the air at sea-level the oxygen will no longer enter into chemical combination with the hæmoglobin. Accordingly, at a height above sea-level at which the atmospheric pressure falls to below half its pressure at sea-level, *e.g.*, about 17,000 feet, breathing becomes difficult.

The oxygen taken up by the hæmoglobin is very loosely combined and is readily captured by the tissues and used for various processes generally to make unstable compounds that break down and require to be built up again; and this incorporation of oxygen with breaking down and building up is the very essence of life.

Between the air and the blood there is of course the filmy wall of the air-cell of the blood-vessel; and it seems probable that the walls play an active part in promoting the interchange of gases, especially the absorption of oxygen.

Condition of Carbon Dioxide in Blood.—Even in arterial blood there are 40 volumes per cent. carbon dioxide, and this might seem to imply that the pressure of carbon dioxide in the blood must be great. This is not the case, however, since the greater part of the carbon dioxide is in loose or in firm chemical combination with the proteids and alkalis of the blood and only 5 per cent. in simple solution.

Vapour.—Besides giving up carbon dioxide to the air the lungs and air-passages give up heat and moisture. However cold or dry the air may be on entering, it is always warm and moist when expired. Even in passing the nostrils the air is warmed and moistened. It is found that air at the temperature of −8° C. is warmed up to 24·5° C. before it reaches the throat, and is saturated with moisture to the extent of one-third of its capacity; and by the time the air has been to the lungs and back again, it is warmed to the temperature of the body and is saturated with moisture. The amount of heat carried off in this way is considerable, and on the average about half a pint of water is discharged in this way. It is evident, however, that the amount in both cases must vary with the coldness and dryness of the air.

Why life should require an interchange of gases—why this interchange should be associated with life—is another question upon which we shall not enter. All we can say is that the combination of oxygen with the tissues results in cell-movement, reproduction, &c., and that without such combination life ceases. If we deprive even the lowest aërobic microbes of oxygen they cease to move and reproduce. The process is a kind of slow combustion, and the carbon dioxide is simply a chemical product of the combustion even as it is a product when we burn a candle or a bit of wood.

It must be noticed, however, that *all* the oxygen absorbed is not used for purposes of combustion, and that *all* the carbon dioxide discharged is not a product of combustion.

A certain amount of the oxygen inspired is stored up in a stable form in the tissues, and a certain amount of carbon dioxide is produced without a corresponding absorption of oxygen. Some of the oxygen absorbed probably combines with fat to make sugar, and some of the carbon dioxide is probably formed in the course of the formation of fat from carbohydrates. It is a remarkable fact, illustrating the first case, that hibernating animals do actually live upon air, and may gain weight without eating simply on account of the combination of oxygen with their fat. And it is an equally remarkable fact, illustrating the second case, that frogs may continue to discharge carbon dioxide even when deprived of oxygen, the carbon dioxide being formed by the decomposition of previously oxidised substance.

As a general practical rule, however, absorption of oxygen and discharge of carbon dioxide proceed *pari passu*, and the carbon dioxide expired may be considered a measure of the intensity of the fire of life. Accordingly, we find that in the most active animals there is the most copious formation of carbon dioxide. In proportion to its weight a worm discharges twice as much carbon dioxide as a frog, a cricket twice as much as a frog, a sparrow five times as much as a cricket, a boy of ten 40 per cent. more than a girl of the same age.

Output of carbon varies also with the temperature of the air, the dietary of the animal, &c.

Let us look now at a few of the circumstances affecting the respiratory exchange.

(*a*) *Muscular Activity.—Ceteris paribus*, we find that the greater the muscular activity the greater the respiratory exchange of the animal in proportion to its body weight. In sleep, for instance, when all the muscular activities are reduced the respiratory exchange is likewise reduced.

During exercise the respiratory exchange is more voluminous than during rest. The necessary concomitant of muscular action is oxidation of the tissues with formation of carbon dioxide, and consequently muscular action is associated with increased uptake of oxygen and output of carbon dioxide.

It must be clearly understood, however, that an increased supply of oxygen will not of itself increase muscular activity; it is a question not of supply but demand.

The term *vital capacity* should be applied not to the respiratory capacity of the lungs as measured by the greatest volume of air they can inspire and expire, but to the respiratory capacity of the tissues as measured by the respiratory exchange: it is not a question of how much can be given to the tissues as how much they can use, and as a matter of fact they have usually more oxygen offered them than they need. Still, granted the capacity of the cells to absorb oxygen, exercise is the greatest stimulant of respiratory exchange, and consequently of tissue change.

E. Smith found that a man discharged 161·6 c.c. of carbon dioxide per minute when he was asleep, 569 c.c. when he was walking at a rate of 2 miles, 851·2 c.c. when he was walking at 3 miles an hour; and 1,581·9 c.c. when he was walking a treadmill. Zuntz and Lehmann found that horses discharged nearly twice as much carbon dioxide when trotting as in walking.

In the course of investigations into the relationship between muscular activity and fatigue, the interesting conclusion was established that any muscular exercise is associated with a smaller output of carbon dioxide if it be frequently practised. This means that practice results in physiological economy, and no doubt to this fact *training* owes much of its value. The increase in the output of carbon dioxide associated with muscular exercise can be maintained only by the consumption of a sufficient quantity of food, since only by food can the wastage of carbon be made good.

Increase of muscular exercise, therefore, is associated with increased absorption of oxygen and increased output of carbon dioxide, and in order to supply material for the interchange both the respiratory mechanism and digestive functions must work more vigorously.

(*b*) *External Temperature.*—Cold weather is usually conducive to muscular activity, and hot weather is apt to cause languor and inactivity. The increased muscular activity produced by cold is of course associated with increased respiratory exchange; but, even apart from the effect of muscular movement, heat and cold affect the respiratory exchange of warm-blooded animals, through the nervous system. As is well known, warm-blooded animals maintain a constant temperature even when the external temperature varies considerably. This constant temperature is maintained by means of variations in the intensity of the oxidative processes in the tissues. In cold weather, quite apart from muscular movement, oxidation and tissue explosion are increased, with a corresponding increase in production of heat and in respiratory exchange; and in hot weather again, quite apart from muscular movement, oxidation and tissue change are reduced with a corresponding reduction in production of heat and in respiratory exchange. If cold or heat be too great this adaptation fails; and great cold may reduce and great heat increase the income of oxygen and the output of carbon dioxide; but within the ordinary limits of climate the law holds good that cold increases and heat decreases tissue change and respiratory output.

In cold-blooded animals, on the other hand, which do not maintain a constant temperature, cold produces no increase of oxidation and of tissue change, and reduces the body temperature and the activity of all the vital functions. In fowls, adaptation to heat and cold are imperfect, and exposure to cold is apt to lower their bodily temperature and reduce their general vitality. The young of many other animals, *e.g.*, pigeons, rats, cats, rabbits, pups, are likewise unable to *react* to cold ; and hence the necessity for maternal nursing.

W. F. Edwards stripped an adult sparrow of its feathers and exposed it and also a fledgling to a temperature of 65°. The temperature of the fledgling quickly fell almost to the temperature of the air, whereas the temperature of the adult sparrow remained at 101°.

Premature babies have almost no reaction to cold, and hence it is necessary to keep them constantly warm.

It must be noticed, however, that a fall of bodily temperature in young animals is less dangerous and detrimental than a fall of temperature in older animals, and that they more quickly regain their temperature under artificial heat.

The following table (from "Recent Advances in Physiology," Leonard Hill) shows the variations in the combustion of the tissues of a mouse, which maintains its bodily temperature when it is exposed to varying temperatures. The table is instructive, being illustrative of the changes which take place in all warm-blooded animals.

Adult Mouse.

Change of External Temperature.	Percentage Increase or Decrease in the Output of Carbon Dioxide.	Interval in which the Increase or Decrease in the Output of Carbon Dioxide occurred.
Degrees.		Minutes.
32·50 to 11·00	+ 211	30
30·00 ,, 10·50	+ 118	10
30·00 ,, 13·75	+ 75	5
30·00 ,, 18·00	+ 74	2
33·25 ,, 17·50	+ 60	1
11·00 ,, 31·50	− 46	30
9·75 ,, 29·00	− 28	10
12·75 ,, 30·00	− 14	5
18·00 ,, 34·50	− 18	2
17·00 ,, 32·00	− 5	1

The inverse relationship between external temperature and output of carbon dioxide, showing lack of reaction to cold in young pigeons, is seen in the following table (also taken from "Recent Advances in Physiology"):—

FIRST-DAY PIGEON.

External Temperature.	Carbon Dioxide discharged in Decigrammes.	Remarks.
36·0	79	Pigeon slightly active
36·0	70	Pigeon quiet
36·0	70	
22·0	46	Pigeon active at first, then quiet
21·5	25	Pigeon quiet

In the warm-blooded adult the regulation of temperature by internal combustion is by means of the nervous system, and all circumstances which deaden or dull the nervous system interfere with this regulation. Thus during sleep, when nervous impressions are dulled, there is much less reaction to cold; and so cold during sleep is particularly dangerous. In cases of great cold sleep may be quickly fatal, for the temperature, no longer regulated by nerve control, may fall below the level necessary for life. Hence the danger of sleeping when lost in the snow. "The activities of the tissues, once the nervous control is lost, are reduced by the cold; chemical change and the production of heat become less and less, until on internal temperature about 20° is reached, when life ceases."

Anæsthetics, like sleep, diminish nerve control, and exposure to cold when under anæsthetics is particularly dangerous, since there is no reaction, and the body temperature quickly falls.

(*c*) *Size and Surface of Animals.*—The size and surface of an animal affect the respiratory exchange merely indirectly through their relationship to bodily temperature. *Ceteris paribus*, smaller animals have a more voluminous respiratory exchange than larger ones because the surface of smaller animals is greater in proportion to their weight. A small round cell is almost all surface, but the larger it becomes the smaller proportion does its surface bear to its total bulk. A cube 1 inch square has 6 inches of surface for its square of 1 inch, whereas a cube 3 inches square has only 2 inches of surface for each of the 27 squares of 1 inch it contains.

The result of the relatively larger surface of the smaller animal is a greater relative escape of heat by radiation from its surface, and hence the animal has to burn more—has to effect more voluminous respiratory exchange—in order to maintain its temperature. A little, compact man may not be hotter than a long, lanky man, but he has to produce more heat; and hence little men are often more active than big ones and eat more in proportion to their size. A sparrow eats more in proportion to its size than a hen: it is also obviously more active, and its output of carbon dioxide is in proportion eight or nine times as great. A sparrow may be said to burn not so fast as a candle, but about eight times as fast as a hen, and about thirty times as fast as an average man, and more than forty times as fast as the average woman. We have said that the smaller animal is obliged to have more chemical activity in order to maintain its temperature; but perhaps a more logical and scientific way of stating it would be to say that the smaller animal has more relative superficial exposure to cold, and is therefore stimulated to more organic activity functional and chemical.

(*d*) *Diet.*—The oxygen absorbed from the air enters into combination with the substances built up out of the food; and thus the character of the food has a great influence on the character and amount of the respiratory exchange. During fasting the respiratory exchange is reduced to a minimum and after food it increases rapidly. The amount, however, of the increase after food depends largely on the nature of the food taken. If the food be fat the increase in the respiratory exchange is less than 10 per cent., while, on the other hand, if the food be proteid or carbohydrate there may be a rise of 50 per cent., or more. When the food is carbohydrate the volume of carbon dioxide discharged is greater than the volume of oxygen absorbed.

(*e*) *Age*.—As age increases, the respiratory exchange grows less, both because muscular and functional activity are diminished. A youth of 19 will discharge nearly 20 per cent. more carbonic dioxide in proportion to his weight than a stoutish man of 60; and the same relationship holds good in the female sex.

The question of the relationship between atmospheric pressure and respiratory exchange will be discussed in a separate chapter.

Regulation of Respiration.—The respiratory function is mainly automatic. Night and day we go on breathing, and night and day this wonderful process of oxidation goes on, and we are not aware of it. But, further, it is also regulated so that the rate or depth of breathing is altered to suit the needs of the organism. Exercise, as we have seen, implies an increased consumption of oxygen and an increased output of carbon dioxide, and during and after exercise both heart and lungs act more vigorously.

Now, how is the mechanism of respiration regulated? On what principle does it respond to the needs of the organism? The regulation is of course nervous and depends, as we have already mentioned, on the nerve centre situated at the top of the spinal column.

But how does the nerve centre gain information as to the respiratory requirements of the individual?

The information is gained by the respiratory centre from two sources—from the blood, and from the nerves. Blood goes to the respiratory centre and nerves go to the respiratory centre. The blood gives information as to the amount of oxygen and carbon dioxide in the blood; and the nerves give information as to the mechanical working of the respiratory apparatus, as to the temperature of the skin, &c.

It has been proved that filling of the lungs causes the mechanism of *expiration* to come into play, and that emptying of the lungs causes the mechanism of *inspiration* to come into play; and thus the alternate rhythm is maintained. This is a nerve reflex: the respiratory centre responds with motor impulses to messages sent to it from the lungs by means of the nerves which supply the lungs.

It is probable that this nervous reflex action is the chief cause of the steady rhythmical action of the lungs; but it is probably the blood (not the nerves) which regulates the *rate* and *depth* of the respiration—what may be called the ventilation of the lungs. It has been proved that the respiratory centre is particularly sensitive to carbon dioxide in the blood, and that any increase in the amount of carbon dioxide in the blood causes a corresponding increase in its respiratory activity. Thus the carbon dioxide in the blood is really a respiratory stimulant and helps to get rid of itself.

If the pressure of the carbon dioxide in the blood fall below a certain point breathing will cease for a while, until more carbon dioxide accumulates or until the supply of oxygen becomes too low. Any one who tries to hold his breath and so causes an accumulation of carbon dioxide in the blood will quickly discover how strongly the involuntary motor impulses of respiration will fight against his will. It is a very remarkable self-regulatory device, and it is a pity that a mechanism for ventilating a room cannot be devised on a similar plan.

Heat and cold, as we have seen, increase or diminish the vital chemistry of the organism and provoke or prevent exercise, and thus, through consequent variations in the amount of carbon dioxide produced, stimulate to a varying degree the centre of respiration. No doubt also they act indirectly through their effects on the circulatory system; but this is less important. Their influence on the respiratory centre is therefore chiefly indirect; but sudden cold, such as a cold draught or a cold douche, may directly affect the respiratory centre through the afferent (*i.e.*, the nerves that take messages from the surface to the central nervous system) nerves.

These are the main regulating factors, but there is no function in the body more open to reflex interference. As Foster well put it: "The respiratory centre responds in fact in the most intricate and varied manner to nervous impulses proceeding from all parts of the body, and thus delicately adjusts the working of the respiratory pump to the needs of the economy."

The reflex adaptability of the respiratory mechanism is shown in a hundred ways. Does not a douche of cold water make one gasp? Does not a grain of snuff, sometimes even exposure to bright light, make one sneeze? Is not an indiscretion in diet a common cause of an asthmatic attack? Is not a cough sometimes even of ovarian origin? Does not the alteration of the blood in diabetes cause that condition known as air-hunger? Nor is the interference necessarily mechanical or chemical. It is well known that emotions of fear or of surprise may take away the breath, and it has lately been shown that certain kinds of music may deepen inspiration.

Strangely enough, the relationship between exercise and breathing is still under debate. That it quickens breathing and increases the respiratory exchange is well known; but there seems some doubt as to the precise way in which the respiratory centre is stimulated. It is rather doubtful whether the stimulant is excess of carbon dioxide in the blood, since the increased ventilation of the lungs and quickened action of the heart quickly discharge any excess of carbon dioxide; and it seems likely that the respiratory centre is stimulated by the products of muscular waste carried to it by the blood, and that the chief stimulant is lactic acid.

Relationship between Heart and Respiratory Mechanism.—The relationship between the heart and the lungs has already been explained. The blood is the carrier of the oxygen from the air to the tissues and the carrier of the carbon dioxide from the tissues to the air, and the heart it is that pumps the blood through the tissues. If, accordingly, the blood is deficient in carrying power (*i.e.*, is deficient in hæmoglobin), or if the heart is deficient in propelling power (*e.g.*, suffers from fatty degeneration or leaks), the tissues receive insufficient oxygen, with the result that carbon dioxide accumulates in the blood and stimulates the respiratory centre to increase the ventilation of the lungs, producing that panting habit known as short-windedness.

And one of the chief symptoms of loss of blood from any cause is shortness of breath. Those with heart disease are likewise short-winded, because, even though the blood may be rich enough in hæmoglobin, it does not circulate with sufficient rapidity to be sufficiently oxidated or sufficiently purified by carbon dioxide.

The importance of the heart and circulation as part of the respiratory mechanism cannot be overestimated, and if we find a man short-winded the probability is not that his breathing is deficient, but that his heart or blood are not doing their work competently. Athletic performances that test the breathing power require not only that the lungs should have good ventilating capacity, but also—and this is still more important—good blood and sound heart working harmoniously with the respiratory functions proper.

CHAPTER IV

AIR PRESSURE IN ITS RELATIONSHIP TO LIFE

THE pressure of the atmosphere, amounting to 15 lbs. to the square inch, has plainly great physiological importance. All the tissues and fluids of the body are subjected to this pressure and in equilibrium with it, and, as we have seen, even the interchange of gases on which life depends is largely a phenomenon of atmospheric pressure.

A.—DIMINISHED ATMOSPHERIC PRESSURE

Let us look first at the principal physiological effects of *decrease* in atmospheric pressure.

The smaller variations, such as occur day by day at sea-level, implying perhaps a diminution of pressure to the extent of half a pound or a pound to the square inch, have no very obvious physiological effects. In the case of patients subject to pulmonary hæmorrhage a sudden alteration of pressure even to that extent may perhaps conduce to hæmorrhage; but the ordinary healthy man is unaffected by such everyday fluctuation. Greater variations, however, such as are associated with great heights, have physiological effects more or less striking, due chiefly to a diminution of oxygen. Oxygen, in accordance with laws we have stated in a previous chapter, passes from the air in the air-cells into the blood in volumes proportionate to the difference between the oxygen pressure in the air-cells and the oxygen pressure in the blood. Under ordinary conditions this difference of pressure is about 35·5 mm. of mercury—a pressure much more than sufficient to provide by solution all the oxygen the blood-cells can carry away, and it is probable that even in the rarefied air on the top of Mount Everest enough oxygen would be in solution in the blood to supply the red blood-cells. But another factor must be considered. The appetite of the blood-cells for oxygen diminishes considerably as pressure diminishes. Thus at ordinary atmospheric pressure at sea-level the blood-cells are about 80 per cent. saturated with oxygen; but if the pressure fall to ¼ atmospheric pressure the blood-cells are content with 70 per cent. and if it fall to ⅛ atmospheric pressure their capacity is reduced to 50 per cent. of full saturation. Owing to this fact, the higher we go or the rarer the air becomes, the less oxygen is seized by the blood-cells, and consequently at great heights breathing becomes difficult. The influence of pressure on chemical combination is well known. Frankland and Tyndal found that stearic candles burnt away more slowly on Mont Blanc than on the plain, Dr. A. Benedicent proved that an oil light which consumed 2·1930 grammes of oil at sea-level consumed only 1·9119 grammes at a pressure corresponding to an altitude of 5,950 metres.

This then—a diminution in amount of oxygen absorbed—may be considered the most important effect of diminished atmospheric pressure.

The diminution of oxygen due to ascent is gradual, and under ordinary conditions, at reasonable heights, the organism can adapt itself to the altered atmospheric conditions.

At heights where the oxygen pressure is insufficient there are deepened breathing and quickened pulse-rate. Deepened breathing and a quicker pulse-rate are indeed two of the most constant effects of diminished atmospheric pressure. The deepened breathing increases the pressure of the oxygen in the air-cells and the quickened respiration carries the oxygen more quickly to the tissues.

The quickened pulse-rate is particularly noticeable. Dr. Huggard, in his work on climatic treatment, gives an interesting account of Wood's observation of his pulse on the Plateau of Pamir, 15,600 feet above sea-level.

"One evening sitting quietly in his tent he chanced to feel his pulse. Its rapid and tumultuous action attracted his attention, and he thought he was in a violent fever. Next morning he found the pulse as quick as the evening before; nevertheless he felt perfectly well. He then examined the pulse of his companions, and to his surprise found that in each case it was more rapid than his own. Afterwards he counted his pulse whenever he registered the boiling-point of water, and found that the pulse-rate was a kind of living barometer, by which a man accustomed to observe himself might at great altitudes roughly calculate the height."

Pulse-rate on the Pamir, 15,600 feet.

Self (Wood)	110	Scotchman, stout
Gholam Hussein, munshi	124	Jasulmeere, ,,
Omer-Allah, muleteer	112	Afghanistan, thin
Gaffer, servant	114	Peshawuree, ,,
Dowd	124	Kabul, robust.

In 1894 Professor Kronecker, of Berne, arranged that eleven persons should be carried from Zermatt (1,600 metres) to the plateau of the Breithorn (3,750 metres). In every case the heart-beat was quickened. M. Lortet, of Lyons, found that his pulse-rate, which was 64 at Lyons, increased to 90–108 on Mont Blanc.

Not only is the average pulse-rate quickened, but the heart is more excitable and is much more easily accelerated. Most of Kronecker's cases found that slight exercise was sufficient to cause palpitation; and a soldier in Turin who could raise dumb-bells 121 times with an increase of pulse-rate of only six beats, found that the same exercise on Monte Rosa increased his pulse-rate from 94 to 120.

The quickened pulse-rate is of course physiological and compensatory, but if the heart be weak or diseased it may fail to achieve the extra work, breathlessness may continue, or even heart-failure ensue.

Most plants, and even some animals (especially shallow-breathing animals), are unable to accommodate their physiological functions to very high altitudes. Plants on high mountains tend to become like desert plants: their roots hypertrophy and their parts aboveground are dwarfed and stunted. In the Alps the forests end at about 6,000 feet. Cats will not live above a certain height. "They sicken in the villages of the Cordillera; become dejected, have convulsions of an epileptic character, and finally die." Rabbits and guinea-pigs are equally unable to live at very high altitudes. Man, on the other hand, seems to have remarkable capacity to accommodate himself to diminished atmospheric pressure. "The highest dwelling-place continuously occupied is the Observatory El Mirti, in the Andes, at 5,880 metres. The Observatory at Arequipa is at 6,100 m. Thok djalung is a village in the Himalayas at 4,980 m. In Peru, Bolivia, and Northern Chile a very large part of the population live above 3,000 m. Potosi, which has numbered 100,000 inhabitants, is at 4,165 m., Cerro de Pasco at 4,350 m., the mines of Villacota at 5,042, the railway from Callao to Oroya culminates in a tunnel at 4,760 m., almost the height of Mont Blanc. . . . An annual fair is held at Gartok, at 4,598 m., in the Himalayas, to which thousands annually come" (Leonard Hill, "Recent Advances in Physiology").

And there are Buddhist monasteries in Thibet at a still greater height.

Boussingault remarks: "After looking at the bustle of traffic in towns like Bogota, Micuipampa, Potosi, and suchlike, at elevations of 8,000 to 12,000 feet; after witnessing the strength and the marvellous skill of the toreadors in the bull-fights at Quito, 9,000 feet above sea-level; after seeing young and delicate girls dancing a whole night at places as high as Mont Blanc, on which the celebrated Saussure had hardly strength enough to use his instruments of observation and his hardy guides fell down in a swoon as they proceeded to dig a hole in the snow; when we remember, finally, that a famous battle, that of Pinchincha, was won almost at the altitude of Monte Rosa, I think that you will agree with me that man can become adapted to breathing the rarefied air of the very highest mountains."

Effect of diminished Atmospheric Pressure on the Blood.—One important physiological effect of diminished atmospheric pressure is a remarkable increase in the number of the red blood-cells; and this increase is probably of a compensatory character, enabling the blood to absorb a larger amount of oxygen at a lower pressure. Bert was the first to discover this; he found that animals living in Mexico at 3,700 m. had double the normal number of red blood-cells. Viault found that the llama had 16 million red blood-cells, and that in Peruvians living at a height of 4,392 m. the red blood-cells numbered about 50 per cent. more than normal. Many observers have confirmed this increase, and the following table, compiled by Dr. Huggard in his work on climatic treatment, gives an instructive summary of various observations.

(The average number of red blood-cells is 5,000,000 per cubic millimetre.)

Place.	Altitude in Metres.	Red Blood Corpuscles per Cubic Millimetre.	Observer.
Christiania ...	Sea-level	4,974,000	Laache
Göttingen ...	148	5,225,000	Schaper
Basle	266	5,169,000	Karcher
Tübingen ...	314	5,322,000	Reinert
Zürich... ...	411	5,752,000	Stierlin
Goerbersdorf...	561	5,800,000 in healthy men...	Jaruntowski and Schroeder
		5,244,000 ,, ,, women	
Serneus ...	985	6,084,000	Suter
Champéry ...	1,052	5,712,000	Karcher
Leysin ...	1,450	6,048,000 in healthy men...	Radovici
		5,760,000 ,, ,, women	,,
Davos	1,560	6,551,000 ,, ,, men...	Kündig
		5,804,000 ,, ,, women	,,
		6,290,000 ,, ,, men...	Van Voornveld
		5,595,000 ,, ,, women	,,
Arosa	1,800	7,000,000 (min. 6,350,000 to max. 7,320,000) in ten healthy men	Egger
		6,500,000 in one healthy woman ...	,,
		6,529,000 in five healthy men	Roenisch
		6,315,000 in two healthy women ...	,,
Cordilleras ...	4,392	8,000,000	Viault

Professor Jaquet in Basle and Dr. F. Suter in Davos made together an interesting experiment with rabbits. Rabbits were kept for four months in Davos and Basle under similar conditions. After four months both lots of rabbits were killed and their blood compared. The following table, showing the result, shows that the blood of the Davos rabbits was greater in quantity and richer in quality.

	Basle.	Davos.	Difference per cent.
Blood corpuscles per c.mm. defibrinated blood	5,478,000	6,204,000	13·25
Hæmoglobin per cent.	13·23	14·47	9·37
Hæmoglobin entire amount in grammes	12·07	14·85	23·03
Hæmoglobin in thousandth parts of body weight	5·39	6·59	22·26
Quantity of blood (cubic centimetres) ...	90·66	104·15	14·88
Quantity of blood in thousandth parts of body weight	0·74	45·97	12·95
Dry residue of blood serum per cent. ...	6·89	7·13	3·65

Müntz made a similar comparison between the blood of rabbits kept on the plain and rabbits kept on the summit of the Pic du Midi, and found the blood of the rabbits from the Pic du Midi much the richer in hæmoglobin.

The increase is due, not to any of the concomitants of height such as increase of sunlight or decrease of humidity, it is due mainly, if not altogether, simply to the diminished atmospheric pressure, for a similar change in the blood has been produced by keeping rabbits and guinea-pigs in rarefied air at sea-level.

M. Paul Regnard took two guinea-pigs of the same litter; one he kept under a well-ventilated bell-glass in which the atmosphere was reduced to a density corresponding to a height of 3,000 metres above sea-level, the other was kept at ordinary atmospheric pressure. After a month both guinea-pigs were killed, and it was found that the blood of the guinea-pig which had lived in the rarefied atmosphere absorbed 21 c.c. of oxygen per 100 c.c. blood, whereas the blood of the other guinea-pig which had lived under normal atmospheric pressure absorbed only 14 or 15 c.c. of oxygen.

The fact seems to be quite indubitable that diminished atmospheric pressure increases the number of red blood corpuscles; though *how* the increase is brought about is still a matter of debate. The increase occurs rapidly and reaches its full amount in about ten days or a fortnight, and it is probably not permanent.

We see, therefore, that the human organism, by acceleration of circulation, deepening of inspiration, and increase of red blood corpuscles, endeavours to compensate for the lower pressure of oxygen at diminished atmospheric pressures, and the question at once suggests itself—how far does compensation go, and does the total respiratory exchange at diminished atmospheric pressure equal or exceed the total respiratory exchange at the atmospheric pressure of sea-level? Experiments have been made by Loewy, Zuntz, Mermod, and others to settle this question, but so far the results have been rather contradictory. Zuntz found that his respiratory exchange at rest was from 15 to 50 per cent. greater on Monte Rosa than at Berlin, and that exercise on Monte Rosa caused a correspondingly greater increase in his respiratory exchange. Aggazzotti, on the other hand, found no increase in the respiratory exchange of guinea-pigs kept at high altitudes, and Mermod, who made careful observations for some months, found that though rate and depth of inspiration increased with altitude, the total interchange of gas decreased.

On the whole the evidence seems to point to diminished respiratory exchange under lowered atmospheric pressure, and seems further to suggest that when the respiratory exchange is increased at high altitudes—as it usually is—the increase is due to sunlight, cold, electrical conditions, and not to the diminished pressure of oxygen. Thus it would seem that on the heights life may be less vigorous and intense than on the plains. Nor is this surprising, for oxygen is the breath of life, and certainly oxygen under high pressure is more readily available for the tissues.

Effect of diminished Atmospheric Pressure on the Nervous System.—Any effect on the nervous system is indirect, and must depend chiefly on the oxygen exchange. The general effect seems at first to be stimulating and exciting, but after a time, when a compromise has been effected between oxygen supply and tissue demand, the stimulating and exciting effect seems to pass off. One certainly cannot hold that the Alpine highlanders are habitually more excitable and energetic than the inhabitants of the plains of Italy. De Saussure, it is true, says that when living at the Col du Géant, at a height of 11,020 feet, "it seemed to my son and me that in our physical observations we worked with distinctly freer and more active spirit, and that the mind was less easily fatigued, I will even say more inventive, than on the plain," but it must be noted that he stayed at this height only for a fortnight, and that he admits that "It seemed to me that in general the nervous system was more irritable, and that we were more liable to impatience and to outbursts of anger." It may well be doubted—especially in view of the diminished respiratory exchange—whether the stimulating effect of high altitudes is likely to prove permanent. If the organism fail, through weakness of the heart or from any other cause, to acquire sufficient oxygen, the nervous system quickly suffers, and at very great reduction of atmospheric pressure nervous debility and disturbance is inevitable.

"At very great elevations," writes Huggard, "balloonists and mountaineers have remarked noises in the head and giddiness, impairment of the senses of sight, hearing, and touch, dulness of the intellectual faculties, slowness in mental perception, difficulty in making simple calculations, and a strong desire to sleep;" and he quotes Robertson, the French physicist and balloonist, who writes: "At this elevated point (23,517 feet high in a balloon) our condition was one of indifference; there the physicist is no longer alive to the glow and to the passion of discovery; the danger arising from the smallest negligence hardly occupies him. Only with the help of a little bracing wine does he manage to regain some interests of intelligence and of volition."

Mosso succeeded in enduring, with the aid of oxygen, an atmospheric pressure reduced to 192 mm. At this pressure he writes: "My handwriting is little altered. I do not tremble nor feel sick nor sleepy, but overcome with apathy. My lead-pencil, which I lay on the table, rolls off and falls into a pail of water in which are the tubes of the bottles which serve to collect air for subsequent analysis.

Seeing that I have no means of continuing to write unless I stoop to pick up the pencil, which is too much trouble, I break off the experiment although my condition is less distressing than the first time."

At a height of 29,000 or 30,000 feet consciousness is lost, and death ensues even in the case of specially trained subjects. All this might be expected; for both mental and physical function depend upon the absorption and synthesis of oxygen, and this, as we have seen, becomes increasingly difficult with decrease in the oxygen pressure. By inhaling oxygen much greater heights can be reached than could be otherwise attained; and it may be mentioned that in his recent expedition to the Himalayas, the Duke of Abruzzi included in his equipment a portable oxygen inhaler.

Mechanical Effects of diminished Pressure.—The mechanical effects of diminished pressure are almost nil. The pressure of the internal gases diminishes as the atmospheric pressure diminishes and equilbrium is completely preserved.

Mountain-sickness.—Mountain-sickness was first described by a Jesuit missionary, Acosta. Writing four hundred years ago, he says: "While ascending a mountain in Peru I was suddenly affected by so strange and so mortal an evil that I nearly dropped from my horse to the ground. . . . I was alone with an Indian and asked him to help me to keep on my animal, and I was taken with such pain, sobbing, and vomiting, that I thought I should die, and moreover, after having vomited food, phlegm (mucous matter), and bile, yellow first and afterwards green, I even threw up blood, such pains had I in my stomach; and I am sure that if it had lasted longer I should certainly have died. As it was it lasted only three or four hours, till we had reached a much lower region. And not only men but animals also were affected." And he declares: "I feel confident that the substance of the air in such places is so subtle and thin that it is unsuitable for human respiration, which requires it thicker and better adapted."

Acosta was right in his theory, and the group of symptoms which affected him, and which is now known as mountain-sickness, is certainly the result of "too thin" air.

How exactly the disorder is caused is still, however, a subject of debate. It occurs in various people at various heights and with varying degrees of severity; and its occurrence seems to depend on the condition of the individual. Fatigue certainly increases liability to the disorder, and the writer, who has frequently climbed to 10,000 feet without bad effects, once suffered from mountain-sickness at the height of 7,000 feet after an extremely fast and fatiguing ascent.

Bert and Jourdanet, who made a thorough study of mountain-sickness, came to the conclusion that it was due to lack of oxygen, and though it is difficult to understand on this theory how mountain-sickness should occur at comparatively low altitudes, yet there is no doubt that oxygen relieves the symptoms, and that if oxygen be kept at good pressure, very low atmospheric pressures may be endured without discomfort. Bert kept a bird alive in oxygenated air, even though the pressure was reduced to less than $\frac{1}{10}$ of an atmosphere.

This theory of lack of oxygen in the blood is most commonly held; but two others should be mentioned. Kronecker holds that the symptoms are due to impeded pulmonary circulation, and Mosso believes them due to lack of carbon dioxide in the blood.

According to Kronecker's theory, the rarefied air has a suction action on the blood-vessels of the lung, causing the lungs to become engorged and congested and impeding the flow of blood through them. A fatal objection to this theory seems to be the fact, already pointed out, that so long as the oxygen pressure is good a great reduction in general atmospheric pressure can be borne.

Mosso pointed out that under reduced atmospheric pressure the blood loses carbon dioxide more quickly than it loses oxygen, and attributes mountain-sickness to this loss of carbon dioxide. Carbon dioxide in the blood is certainly a stimulant and regulator of the respiratory centre; and deficiency of carbon dioxide may play a part in the production of mountain-sickness; but it is very doubtful whether it plays such an important and essential part as Mosso maintains. If deficiency of carbon dioxide be the cause of mountain-sickness, then holding the breath ought to relieve the symptoms, and this is not found to be the case.

Tschudi's theory that mountain-sickness is due to cerebral congestion and Loewy's theory that it is due to cerebral anæmia were both disproved by Mosso, who made some interesting experiments on subjects with holes in their skulls.

B.—INCREASED ATMOSPHERIC PRESSURE

Under ordinary natural conditions of life the body is never subjected to atmospheric pressure much greater than 760 mm., for the habitations of men are rarely below sea-level. A few valleys, such as the valley of the Dead Sea, are below sea-level, but such slight increases in pressure as they show are of no practical importance. Even in the deepest mines the increase in atmospheric pressure has little physiological significance. It is chiefly in the course of operations conducted under water, in diving-bells and caissons, that atmospheric pressures affecting the physiological functions are found. When a diving-bell is lowered 10 metres into the water, the air contained in it is compressed to one-half its original bulk, and the pressure in the air is accordingly doubled. Each 10 metres' depth means an additional pressure of 1 atmosphere. At a depth of 30 metres (about 100 feet), accordingly, a diver is exposed to a pressure of 4 atmospheres. A pressure of 4 atmospheres means about 60 lbs. pressure to the square inch, and it might be supposed that so great a pressure would mechanically impede the physiological processes or would even injure the vitality of the living cells. This, however, is not the case. So perfect is the gaseous equilibrium that even the circulation in the delicate capillaries in the web of a frog's foot is undisturbed by such pressure. Nor are living cells damaged by much greater pressures: at a depth of 7,000 feet the dredge of the *Challenger* brought up Tunicates, Crustaceans, Molluscs, Echinoderms, Worms, Coelenterates, and Protozoa. The mere mechanical effect of increased atmospheric pressure is therefore negligible. Not in this way, but in other more indirect ways, does increase in atmospheric pressure affect life.

According to laws that we have already noticed, an increase in atmospheric pressure means an increase in the amount of the atmospheric gases which are dissolved by the blood, and also an increase in the chemical absorption of oxygen by the red blood-cells. At ordinary atmospheric pressure the red blood-cells are only 81 per cent. saturated with oxygen; and at ordinary atmospheric pressure the fluid of the blood contains ·3 per cent. of oxygen in solution. At a pressure six times as great the red blood-cells will be 96 per cent. saturated with oxygen, and the fluid of the blood will contain 1·8 per cent. of oxygen in solution.

Now what is the effect of this gaseous addition to the blood? Since oxidation is such an essential part of vital change it might be imagined that an increase of oxygen in the blood such as results from increased air pressure would mean an increase in vital change and in respiratory exchange. It has been surmised by certain writers that the lethargic life of the reptilian leviathans of the Carboniferous period was in correspondence with the smaller proportion of oxygen then supposed to be in the atmosphere, and that an increase in the proportion of oxygen is the cause of the more vigorous life of more recent organisms; and it might be supposed that an increase of oxygen might mean increased vitality in individuals as well as in species. We have seen, indeed, that in men and other modern animals a decrease of oxygen leads to debility and languor; we have seen that at a reduced oxygen pressure Mosso had not even sufficient energy to pick up his pencil. Now does the reverse also hold? Does increased oxygen pressure mean increased energy, even as it means an increase of oxygen in the blood?

The answer is of great therapeutic importance; and must be negative. It is found that as in the case of diminished atmospheric pressure so in the case of increased atmospheric pressure there is a great margin of neutral ground. We found that even a very great decrease in pressure of oxygen caused very little decrease in the respiratory exchange; and we find likewise that the respiratory exchange—the measure, be it remembered, of vital activity—is very little increased by increase in pressure of oxygen. Indeed the oxygen may vary between pressures equivalent to one half and three times its pressure in the normal atmosphere without any very marked effect on the vital chemistry; though beyond these limits, up as well as down, the effect is wholly evil.

It may be asked, How is it that an increase of oxygen in the blood does not mean increased oxidation, and hence increased respiratory exchange? The reason is plain. Oxidation is a question of demand and not of supply. In the blood at normal atmospheric pressure there is much more oxygen than the tissues require. To send more oxygen to the tissues is to take coals to Newcastle. One may send oxygen to the cells, but one cannot make them consume it. It is the appetite of the tissues that regulates the consumption of the gas; and the only way to increase oxidation is to increase tissue change.

Ignorance of this principle has given rise to many erroneous ideas. It is thought, for instance, that a man able to breathe deeply is necessarily a strong man; as the term "vital capacity" shows; but vital capacity is shown not so much by the oxygen a man inspires as by the carbon dioxide he expires. There is not much advantage in taking oxygen into the lungs and then blowing it out again, and an increase of a few inches in a man's chest measurement may be quite useless so far as his health is concerned. Still Nature usually adapts her bellows to her furnace, and a *naturally* large chest with good expansion is usually a sign of vital vigour.

In air at a pressure of 5 atmospheres all animal and vegetable organisms are killed. Air at a pressure of 5 atmospheres contains oxygen at a pressure of 1 atmosphere; and oxygen by itself at a pressure of 1 atmosphere is equally fatal to life. Pressure of oxygen higher than this causes irritation and inflammation of the lungs and convulsions. Pure oxygen under the pressure of 3 atmospheres produces inflammation of the lungs in a few hours, under the pressure of 50 atmospheres it causes instantaneous convulsions.

Divers and workers in caissons are never subjected to more than 4½ atmospheres' pressure and work in the caissons for only a few hours at a time, and they do not seem to suffer any ill-effects from their occupation; so far as oxidation is concerned, on the other hand, they used to be liable to a dangerous condition called caisson-disease.

Caisson-disease.—When men came up from high pressures it was found that they were liable to suffer from after-effects of the high pressure—*e.g.*, pains in the joints and muscles, sickness, giddiness, breathlessness, unconsciousness. Sometimes also death followed. Among 600 caisson workers at a bridge in America 14 died and 53 suffered from paralysis of the lower limbs. Among divers similar symptoms are found: divers' palsy is well known; and there are many fatalities among sponge and coral divers.

At first the disease was a mystery, and vain attempts were made to explain it as the result of mechanical pressure; but in 1878 Paul Bert showed exactly how it is caused. As we have seen, considerable amounts of gas are driven into the blood, when the relative pressure of the gases outside the blood is increased. So long as the outside pressure remains great, the blood retains the gas quietly in solution just as the water in a bottle of aërated water retains its gas till the pressure is reduced. But if the pressure of the gases outside the blood is suddenly decreased, then the gases escape from the blood and the blood bubbles and effervesces just as a bottle of aërated water bubbles and effervesces when the cork is drawn. Now when a man who has been under great gaseous pressure below water is quickly brought above water where the pressure is much less, the gas begins to bubble in his blood and to escape, and the result is that bubbles may collect where their presence is dangerous or distressing, or painful, *e.g.*, in the labyrinth of the ear, in the spinal cord, in the heart.

The disease, then, is due simply to an effervescence of gases in the blood, and if the diver or caisson worker is brought up slowly, so that the bubbles of gas may be absorbed as they escape, then the symptoms of caisson-disease no longer occur.

The more rapid the change from high to low pressure—*decompression*, as it is called—the more likely is damage to occur; and if decompression be slow enough great pressure can be borne without harm. Paul Bert was subjecting a dog to a pressure of 9½ atmospheres when the apparatus burst. The dog instantly died, and its heart was found to be full of gas. On the other hand, Bert frequently subjected dogs to a pressure of 10 atmospheres, and then slowly decompressed them without harm.

CHAPTER V

TEMPERATURE OF THE AIR, AND HEALTH

MAN is but a thermal product of the cooling world, as dependent on temperature as a bubble on a frying-pan. For thousands of millions of years the world was too hot for him, and by and by it will be too cold. Not only does heat move the winds and the seas: it also moves the little molecules into the dancing combinations on which the manifestations of life depend; and above and below certain temperatures life is impossible. The heat of the hen's bosom charms the egg into a chick, and without heat it would remain an egg and possibly become a very bad one. But again, if we boil the egg the chick perishes for ever. Heat, in fact, seems the form of energy most directly connected with the energies of life; all the physical functions are associated with the presence and production of heat, and can be measured in terms of heat.

The production of heat by the living organism is one of the most constant of the phenomena of life, and nothing is more remarkable than its steady regulation at a certain point in the case of hot-blooded animals. All through life a healthy man's body maintains a temperature of about 98·6° F., and if the body heat increases or decreases a few degrees the man dies. He goes with a Shackleton to the South Pole and faces frosts perhaps 75° F. below zero; he goes with a Stanley to darkest Africa and faces a heat of perhaps 120° F.

in the shade, and yet his temperature hardly alters—it is still 98·6. Despite changes of about 200° in the outside temperature the temperature of the body remains the same. For short periods still greater variations can be borne by the human organism without much disturbance of the bodily temperature. A famous "Fire King," named Chabert, was able to enter an oven at a heat of 400° F., and workers in foundries have sometimes to endure a heat of 250° F. It is amazing to think that the body can maintain a temperature two or three hundred degrees lower than its environment, merely by the physiological variation of heat production and heat loss. Nevertheless, the outside temperature is of the greatest importance to the organism, and modifies in many ways its vital processes, and, as we have seen in Chapter III., is one of the most important of the factors which regulate the respiratory exchange.

The relationship of air to temperature is very intimate: it both produces heat in the body by that process of oxidation on which life depends, and it is an important factor in the maintenance and modification of the external heat which is a condition of that oxidation. We wear clothes to protect ourselves from heat and cold, but still more do we wear air for that purpose. Our main source of external heat is the sun, and perhaps the main regulator of that heat is the atmosphere. The temperature of the world depends not only on how much sun heat is received, but also on how much sun heat is retained. For instance, if we expose a piece of black cloth and a piece of white cloth to the same sunlight, the black cloth will become hotter because it will absorb more heat and radiate away less. So also we have seen that the temperature of the sea is more equable than the temperature of the land simply because the sea absorbs heat and so possesses it after the sun has gone. Now, in the matter of absorption and radiation of heat, the atmosphere plays a most prominent part. Between us and the sun is this great sea of air, and as the heat of the sun passes through the atmosphere a certain amount of the sun heat is absorbed. Again, as the heat of the earth is radiated away into space, a certain amount is again absorbed by the atmosphere. Accordingly the air both keeps the heat out and keeps it in: it makes the days cooler and the nights warmer. It is a parasol at noon and a blanket at night; except for it there would be much more violent changes in temperature. Outside the atmosphere one would experience terrible extremes of heat and cold.

As one goes higher into the air and as the air between one and the sun diminishes, the sun's rays become more scorching and the nights become colder. Not only does the rarer and drier and shallower atmosphere allow more sunlight to pass through and also allow more heat to radiate away, but it itself, by virtue of its own expansion, is colder. At Quito, which is 9,350 feet above sea-level, the daily variation of temperature at some periods of the year is no less than 34° F., and in a balloon at the same height the daily range would be still greater.

As is well known, the heat of the sun varies with the obliquity of its rays. When the sunlight beats down from overhead it is much more powerful than when it slants from the horizon. This is due not only to the fact that the oblique rays are less concentrated where they fall, but also to the fact that they are more absorbed in their longer passage through the atmosphere. Hence the greater heat at noon than in the morning; in summer than in winter; in low than in high latitudes.

The power of the air to absorb heat and to store heat depends largely on its humidity—on the amount of water vapour it contains. Water vapour is opaque to the infra-red heat rays, and acts almost like the glass of a hot-house in keeping back heat. Thus near the sea, where the air contains a good deal of moisture, the sun is not so scorching and the nights are warmer than inland; and in some islands the daily and yearly variations in temperature are very small. Not only does water vapour act in this way as a great regulator of temperature, but it is also a great reservoir and carrier of latent heat. When water evaporates a tremendous amount of latent heat is carried up into the atmosphere with the water vapour, and again becomes actual heat when the vapour condenses. An enormous amount of latent heat may thus be carried by damp, warm winds, and it seems to us that the mild climate of Ireland and of the Shetlands may be due to this cause even more than to the Gulf Stream.

The quantity of latent heat stored up in water vapour is almost incredibly great. Dr. Huggard remarks that "an easy calculation shows that every pound of water that is condensed from vapour liberates heat enough to raise the temperature of more than 58 lbs. of lead to its melting-point, or to heat and melt more than 38 lbs. of lead or 5 lbs. of cast iron." The Rev. Dr. Haughton makes a similar calculation that one gallon of rainfall gives out latent heat sufficient to melt 75 lbs. of ice or 45 lbs. of cast iron. Humid air is therefore to be imagined as a veritable furnace of possible heat, and every cloud is in essence a cloud of smoke from unseen fire.

But another element besides water vapour affects the thermic character of air. It has been shown that carbon dioxide is especially opaque to heat, and that a very small increase or decrease of the amount in the atmosphere would have striking consequences.

Arrhenius has calculated that if the atmosphere were deprived of all its carbonic acid—of which it contains only ·03 per cent. by volume—the temperature of the earth's surface would fall by about 21° C., and that this lowering of temperature, by diminishing the amount of water vapour in the atmosphere, would cause a further almost equally great fall of temperature. He has also made the following calculations: "If the quantity of the air should sink to one-half its present percentage the temperature would fall by about 40° C.; a diminution to one quarter would reduce the temperature by 8° C. On the other hand, any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4° C., and if the carbon dioxide were increased fourfold the temperature would rise by 8° C. Further, a diminution of the carbonic acid percentage would accentuate the temperature differences between the different portions of the earth, while an increase in this percentage would tend to equalise the temperature."

Ozone, hydrocarbons, and scents also absorb radiations of dark heat; and the common feeling of stuffiness and heat in a scented atmosphere is therefore shown to have scientific basis. (It is possible that the scent of flowers may help to protect them from cold and from too rapid radiation of heat.)

The temperature of the air depends not only on solar radiation, but also on terrestrial radiation. Some soils throw back the heat into the air at once, other soils and water surfaces absorb the heat and may not give it off till after the sun has gone. The most absorbent soils are sandy soils. The sandy soil of deserts may be heated to even 200° F., and when this hot sand is raised by simoons the shade temperature may rise to 125° F. or more. Even the *colour* of the soil is of importance.

It must be noticed that the atmosphere is peculiarly fitted for the acquisition and retention of heat received from the surface of the earth. It is readily heated by a warm surface of the earth through ascending convection currents;

while if the surface of the earth be comparatively cool it can be cooled only by a slower process of conduction. Further, when hot currents of air ascend and cool by expansion the heat is really only rendered latent and conserved and again becomes actual if the currents descend.

Vegetation, especially forests, also affects the temperature of countries. Thus the summer in Bosnia which has extensive forests is several degrees cooler than in Herzegovina which is disafforested.

The importance of wind in the modification and distribution of heat is well known and need not here be discussed.

The Physiological Effects of Heat.—Man is a warm-blooded animal: his temperature, as we have said, remains the same while the temperature of his environment varies; and this uniformity of temperature can only be maintained by variations in the activity of his vital chemistry. The variations in the activity of his vital chemistry under the influences of heat and cold have already been considered in our discussion of the factors affecting the respiratory change, and we need only repeat here the general statement that as a rule and within certain limits heat reduces and cold augments the oxidative processes on which the manifestations of life depend.

The reduction and augmentation in metabolism is necessarily associated with variations in the individual physiological systems of the body. Thus heat diminishes the appetite and cold increases it; heat depresses the nervous system and cold stimulates it; heat quickens the heart, and cold slows it; heat increases the secretion of sweat and cold decreases it.

The effect of heat depends very much, however, on the humidity or dryness, and on the movement or stillness of the air. Extremes of heat and cold, as is well known, are much more trying when the air is humid than when the air is dry, and extremes of heat are better borne when the air is in motion than when the air is still, while extremes of cold are better borne when the air is still than when the air is in motion. Every one knows how severely cold is felt if a wind is blowing. The wind prevents the continuance of a layer of warm air between the skin and the clothes, and thus abstracts heat directly from the body. "Between the clothing of a man and the fur or feathers of an animal strata of air are enclosed, the temperature of which gradually increases above the outside air, until the layer in actual contact with the greater part of the body is 24° to 30° C. A cold wind quickly reduces the temperature of these different layers. The sailors of Parry's expedition to the Polar Seas found that when the air was perfectly calm they could bear better intense cold, 40°, which would freeze mercury, than a temperature of $-12{\cdot}2$ when there was a wind" (Pembrey, "Recent Advances in Physiology").

The question of humidity and heat will be fully discussed in the next chapter.

CHAPTER VI

HUMIDITY, AND THERMOLYSIS

WATER, like other substances, exists in the gaseous as well as in the solid and liquid states; and the atmosphere always contains a certain amount of the gas of water—"water vapour" as it is called. It is usual to consider water vapour apart from the other gases of the atmosphere; but it is really just as much a gas as oxygen or nitrogen and conforms to the general laws of diffusion, &c., that govern the behaviour of gases. Like oxygen and nitrogen, water gas is quite invisible, but unlike oxygen and nitrogen it is readily condensed at *ordinary* temperatures and then becomes visible as clouds or mist, or dew, or snow, or rain. It is much lighter than the air, having a weight only about $\frac{3}{5}$ the weight of air. Air, accordingly, mixed with water vapour is lighter than dry air.

The amount of water vapour which the air can hold depends on the temperature of the air; the higher the temperature of the air the more water vapour can it hold. At 32° F., for instance, the air can hold $\frac{1}{160}$ of its weight of water vapour; at 59° F., $\frac{1}{80}$ of its weight; at 86° F. $\frac{1}{40}$ of its weight. Roughly, every 27° F. increase of temperature doubles the amount of water vapour the air can hold in proportion to its weight. Hence we see that heat protects against itself, for it loads the air with water vapour, which, as we have seen, absorbs many of the heat rays of the sun. On the other hand, as we mentioned in the last chapter, water vapour contains an immense quantity of latent heat which is given off on condensation.

We have talked of the air *holding* water vapour because the expression is common and convenient; but as a matter of fact the air does not hold water vapour. The air has nothing to do with it: the water vapour is held in suspension and tension simply by *heat*, just as the other gases of the air are held.

The amount of water vapour in the air may be expressed either by its vapour tension, or by its weight per unit volume, or as the ratio of the amount of water vapour in the atmosphere to the amount it could hold at the temperature in question if saturated. Thus we may say that air contains so many grammes of water vapour per cubic foot, or we may say that it is at a tension of so many inches or millimetres of mercury, or we may say that it contains such or such a percentage of the amount of water vapour it is capable of holding. The first two expressions indicate how much water vapour the air *does* contain, and are known as expressions of "absolute humidity"; the third is only a comparative estimate of how much more vapour it *might* contain, and is known as an expression of "relative humidity." The amount of water vapour air can hold *when saturated* at different temperatures, or—what amounts to the same thing—the tension of water vapour at saturation point at various temperatures, has been calculated and recorded in tables. Accordingly, if we can find out how much vapour any sample of air contains, we can compare it at once with the amount known to be contained in saturated air, and can thus at once calculate the relative humidity.

To find the amount of water vapour present in any air, we have merely to cool the air till it deposits moisture—till its "dew-point" is reached. At this temperature it is saturated, and we can find in the tables how much water vapour is contained in saturated air at that temperature, or what is the tension of water vapour at that temperature. Let us give an example. We wish to find out the relative humidity of a specimen of air at 15° C. We cool it down, and at 10° C. it begins to deposit dew. Now we find, by reference to the meteorological tables, that at 10° C. saturated air contains 9·4 grammes water vapour per cubic metre or water vapour at a tension of 9·165 mm. of mercury. Having found these figures, then, we have only to compare them, as we have said, with the figures for saturation as recorded in the meteorological tables.

We found in the case we have supposed that the air contained 9·4 grammes of water-vapour per cubic metre; we look at the tables and see that at saturation point at 15° C. it *could* have contained 12·8 grammes, and at once we can calculate that the air was only 73 per cent. saturated, *i.e.*, had a relative humidity of 73 per cent.

From the vapour tension we can reach the same result. We found that the vapour tension was 9·165 mm. of mercury, and in the tables we find that the tension of saturation at 15° C. is 12·699, and from the ratio of these figures we can again calculate that the relative humidity is about 73 per cent.

Given the relative humidity, it is easy to calculate back again to the absolute humidity. Thus if the "relative humidity" at 30° C. is 80 per cent., and we know (from tables) that the air at that temperature *can* contain 30 grammes per cubic metre, then we can easily calculate that the absolute humidity of the air is 24 grammes (80 per cent. of 30) per cubic metre.

The practical meteorologist, however, usually uses other methods than these we have described in other to determine the humidity of the air: he uses a dry and wet bulb thermometer, and by means of special tables known as *Glaisher's Hygrometrical Tables*, he is able to deduce from their readings the dew-point, vapour tension, and relative humidity of the air.

The principle of the dry and wet bulb thermometer depends upon the fact we have already noted, that when a liquid evaporates it stores up and takes with it immense quantities of latent heat. The liquid in evaporating takes heat from objects near it. When we put a wet cloth to the brow it cools the brow, especially if we add spirits to increase evaporation. When water evaporates through a porous bottle of skin or other pervious material the water inside is cooled. When we spray the skin with a volatile substance which evaporates quickly, so much heat may be abstracted from the skin that the part may be actually frozen. Similarly, if we wrap moist muslin round the bulb of a thermometer the evaporation will cool it, and make it give a lower reading than another thermometer whose bulb is dry. From the difference in the readings, then (which varies with the humidity of the air), the dew-point, vapour tension, &c., can be calculated by Glaisher's Tables.

For example, we find that the dry bulb thermometer registers 50° and the wet bulb thermometer, 45°. We look in Glaisher's Tables for the number opposite 50° and find it to be 2·06. By this number (2·06) we multiply the difference (5°) between the bulb readings; and the resultant number—10·3°—subtracted from 50° will be the dew-point. The dew-point accordingly will be 39·7°.

Having found the dew-point, we can find as before, by reference to ordinary hygrometrical tables, the absolute and relative humidity of the air.

The difference in the tension of water vapour at the temperature recorded by the dry bulb and the tension of water vapour at the dew-point as ascertained will give the *force of evaporation.*

HYGROMETRICAL TABLES (GLAISHER).

I.—TABLE OF FACTORS.

Reading of the Dry-bulb Thermometer.	Factor.	Reading of the Dry-bulb Thermometer.	Factor.	Reading of the Dry-bulb Thermometer.	Factor.
20°	8·14	44°	2·18	68°	1·79
21	7·88	45	2·16	69	1·78
22	7·60	46	2·14	70	1·77
23	7·28	47	2·12	71	1·76
24	6·92	48	2·10	72	1·75
25	6·53	49	2·08	73	1·74
26	6·08	50	2·06	74	1·73
27	5·61	51	2·04	75	1·72
28	5·12	52	2·02	76	1·71
29	4·63	53	2·00	77	1·70
30	4·15	54	1·98	78	1·69
31	3·70	55	1·96	79	1·69
32	3·32	56	1·94	80	1·68
33	3·01	57	1·92	81	1·68
34	2·77	58	1·90	82	1·67
35	2·60	59	1·89	83	1·67
36	2·50	60	1·88	84	1·66
37	2·42	61	1·87	85	1·65
38	2·36	62	1·86	86	1·65
39	2·32	63	1·85	87	1·64
40	2·29	64	1·83	88	1·64
41	2·26	65	1·82	89	1·63
42	2·23	66	1·81	90	1·63
43	2·20	67	1·80	91	1·62

Let us now look at humidity under the categories Relative and Absolute.

Relative Humidity.—The average relative humidity of the air in this country is about 75 per cent. As the air cools at night it can hold less moisture, and therefore its relative humidity becomes greater and greater, and finally the layers of air near the ground become supersaturated and deposit dew. While the dew is evaporating the relative humidity keeps high; but as the air warms and becomes able to hold more moisture the relative humidity falls again.

In winter, in this country, when the air is cool and able to hold little moisture, the relative humidity is higher than in summer when the air is able to hold much more. In winter, in this country, the relative humidity may be 75 per cent. at 2 p.m., and rise to 95 per cent. at midnight, while in summer the relative humidity may be 50 per cent. at 2 p.m. and 75 per cent. a few hours later. In California the relative humidity drops from 100 per cent. at dawn to 22 per cent. at noon. A hot wind, by increasing the capacity of the air for moisture, may lower its relative humidity very quickly. The Föhn wind, when it reaches the Riviera, lowers the relative humidity from 50 to 60 per cent. in an hour or two. At the seaside daily variations in humidity are less than inland, and

II.—Tension, or Elastic Force of Aqueous Vapour in Inches of Mercury for every Degree of Temperature from 0° to 95°.

Temp.	Tension.	Temp.	Tension.	Temp.	Tension.	Temp.	Tension.
0°	·044	24°	·129	48°	·335	72°	0·785
1	·046	25	·135	49	·348	73	0·812
2	·048	26	·141	50	·361	74	0·840
3	·050	27	·147	51	·374	75	0·868
4	·052	28	·153	52	·388	76	0·897
5	·054	29	·160	53	·403	77	0·927
6	·057	30	·167	54	·418	78	0·958
7	·060	31	·174	55	·433	79	0·990
8	·062	32	·181	56	·449	80	1·023
9	·065	33	·188	57	·465	81	1·057
10	·068	34	·196	58	·482	82	1·092
11	·071	35	·204	59	·500	83	1·128
12	·074	36	·212	60	·518	84	1·165
13	.078	37	·220	61	·537	85	1·203
14	·082	38	·229	62	·556	86	1·242
15	·086	39	·238	63	·576	87	1·282
16	·090	40	·247	64	·596	88	1·323
17	·094	41	·257	65	·617	89	1·366
18	·098	42	·267	66	·639	90	1·410
19	·103	43	·277	67	·661	91	1·455
20	·108	44	·288	68	·684	92	1·501
21	·113	45	·299	69	·708	93	1·548
22	·118	46	·311	70	·733	94	1·596
23	·123	47	·323	71	·759	95	1·646

air in forests is 10 or 20 per cent. more humid than air in the open. The difference in the relative humidity of outside cool air and of air in a closed stove-heated room may be very great—as much even as 80 per cent.

It must be noticed that the *relative* humidity bears no constant relationship to the *absolute* humidity. Air may have low relative humidity and yet may contain a considerable quantity of moisture. Likewise air may be quite saturated and yet contain a small quantity of moisture. Air at 20° F. will be *saturated* by 1·3 grains of water per cubic foot, and air at 85° F. containing the same amount of moisture will have a relative humidity of only about 8 *per cent.* There is three times as much moisture in the air at Davos in summer as in winter, yet in summer the relative humidity is higher.

In meteorological tables giving climatic particulars of any town or locality the relative humidity is usually stated, and the reading is usually taken at 9 a.m.

It may be interesting to quote a few figures. The following readings are abstracted from a table given in Dr. Huggard's work on Climatic Treatment :—

The mean relative humidity of Denver for the year is only 42 per cent., and in June it falls as low as 43 per cent. At San Diego, on the coast, the mean relative humidity is 72·9 per cent. ; at Los Angeles, a few miles inland, it is 66·6 per cent. The mean relative humidity of Davos is as high as 79 per cent., and highest, as we have said, when it contains least water. In Egypt the relative humidity is very low. The average relative humidity in the hours from 10 a.m. till 6 p.m. for the four months from December to March was :—

Mena House	51·7
Helouan	42·7
Luxor	36·3
Assouan	30·5

On the high inland tablelands of South Africa the relative humidity is very low. At Bloemfontein its annual mean is 58·5 per cent., and on some parts of the Northern Karroo it must be considerably lower. In the heart of the Libyan desert the relative humidity may be as low as 9 per cent. On the South African coast, on the other hand, the relative humidity is comparatively high: at Cape Town it is 79 per cent., and at Port Elizabeth 75 per cent.

1881–1890.

		Temperature.		Mean Relative Humidity at 9 a.m.	Mean Rainfall, 9 a.m.	No. of Rainy Days.
		Mean Minimum.	Mean Maximum.			
Margate ...	Jan. ...	34·8	43·1	90	1·72	16
	July ...	54·0	68·5	74	2·12	14
	Year ...	43·7	54·6	82	23·31	169
Brighton ...	Jan. ...	35·0	44·8	87	2·67	16
	July ...	55·1	67·9	77	2·60	12
	Year ...	44·2	55·7	80	28·75	159
Ventnor ...	Jan. ...	37·4	45·7	88	2·60	16
	July ...	55·3	67·0	79	2·11	14
	Year ...	45·5	56·1	81	28·13	164
Bournemouth	Jan. ...	34·4	44·7	85	2·47	14·3
	July ...	54·2	71·0	69	2·07	14·3
	Year ...	42·6	57·1	77·7	27·60	158·3
Sidmouth ...	Jan. ...	36·2	45·5	91	2·86	18
	July ...	53·1	65·7	82	2·92	18
	Year ...	43·5	54·9	85	32·44	204
Lowestoft ...	Jan. ...	33·8	42·6	91	1·44	15
	July ...	52·5	67·4	75	2·74	15
	Year ...	42·2	53·9	83	24·16	173
Buxton ...	Jan. ...	30·0	40·1	92	4·66	17
	July ...	48·4	65·1	78	4·43	16
	Year ...	37·7	51·6	85	49·31	196
Regent's Park	Jan. ...	33·8	42·9	89	1·91	15
	July ...	53·8	71·0	73	2·68	15
	Year ...	42·4	56·1	81	25·17	165
Blackpool ...	Jan. ...	33·5	42·5	90	2·96	19
	July ...	52·8	64·3	78	3·62	17
	Year ...	41·9	52·9	84	34·23	194
Guernsey ...	Jan. ...	39·7	47·0	89	2·99	17
	July ...	55·1	66·5	83	2·12	13
	Year ...	46·9	56·1	85	32·53	179

These facts are no doubt interesting, but the value of such statistics for comparative purposes is much diminished by the fact that the readings are often recorded at different times of day. The English readings we quoted were taken at 9 a.m., when humidity is about its highest and cannot be compared with the Egyptian readings taken throughout hot, sunny days. It is indeed difficult to see what value can attach to single readings at all when, as we have mentioned, relative humidity may decrease from 100 per cent. at dawn to 22 per cent. at noon, and may be quickly altered to the extent of 50 per cent. by a warm wind.

But even if the relative humidity be comparably and correctly recorded, the record is of only limited value. It may be interesting to know that air is 79 per cent. saturated with water vapour, but the fact has little therapeutical significance; and the man in the street who says that Davos has a dry air is nearer the truth than the man who says that it has the high relative humidity of 79 per cent. What we wish to know are the *physiological* relationships of humidity—how it affects the heat loss and water loss of the body, and when we say that the relative humidity of air is 50 per cent. or 75 per cent. we give little or no physiological information at all. When the meteorological tables record relative humidity they merely mislead the public.

What we wish to know is not how dry the air is compared with how wet it *might* be, but—what is far more important—how *drying* it is. What we wish to know is not how much moisture the air holds, but how much it still can hold, and relative humidity gives us little information on this point.

Dr. Huggard writes: "But the really essential point is, not the amount of moisture relative or absolute that is present, but the amount that can be still taken up. This varies enormously with the same degree of relative humidity at different temperatures, as the following table from Renk will show":—

Amount of Vapour that can still be taken up at different Temperatures and the same Relative Humidity.

Temperature.	Relative Humidity.	Absolute Humidity Grammes per Cubic Metre.	Grammes of Vapour that can be still taken up.
° C.	Per cent.		
—20	60°	0·638	0·426
—10	60	1·380	0·920
0	60	2·924	1·950
10	60	5·623	3·749
20	60	10·298	6·866
30	60	18·083	12·056

We see by this table that the same expression—60 per cent. relative humidity—might be applied to air capable of taking up ·426 gramme and 12·056 grammes of vapour, and thus the expression as a measure of the drying capacity of the air is obviously misleading.

Dr. Huggard gives a second very instructive table, the obverse of the above.

Temperature.	Relative Humidity.	Vapour Grammes per Cubic Metre—	
		Present.	Capable of being taken up.
° C.	Per cent.		
3	0	0	6
10	36	3·4	6
15	53	6·8	6
20	65	11·2	6
25	73	16·9	6
30	80	24·1	6

We see from this second table that air with relative humidities of 0, 36, 53, 65, 73, and 80 per cent., and containing quantities of water vapour varying between 0 and 24·1 grammes per cubic metre are all capable of taking up exactly the same amount of vapour. Again the expression of relative humidity is misleading.

Certainly the amount of vapour which the air is capable of taking up is much more important than the percentage of full saturation it holds, and it can be quite readily indicated by subtracting the tension of the aqueous vapour at dew-point from the tension of the aqueous vapour at the dry bulb temperature; and a record on this principle would have much greater value than relative humidity records.

Absolute humidity? The measure of absolute humidity is useful chiefly as a measure of the thermal conductivity of the air, and of its power of absorbing heat. The greater the absolute weight of moisture the air contains, the more effectively will it conduct and absorb heat. Air with a high absolute humidity, accordingly, will keep heat in the air and render a climate equable. At high temperatures, moreover, it will hinder radiation from the body, and make the air appear close and muggy, and at moderately low temperatures it will conduct heat from the body and will thus render cold more trying. At high temperatures its interference with radiation from the skin more than compensates for the extra heat it conducts away, and at low temperatures the extra heat it conducts away more than equals the heat it prevents from radiating. This is due to the aforementioned fact that in hot weather the disposition of the blood in the skin is favourable to radiation, and interference with this means of escape is therefore a serious matter, while in cold weather the disposition of the blood in the skin is unfavourable to radiation and thus interference with radiation has little effect.

Absolute humidity also interferes with evaporation; but, as we have seen, this interference is *measured* not by the absolute humidity of the air but by the amount it falls short of complete saturation.

As we have explained, meteorologists deduce absolute and relative humidity from the readings of wet and dry bulb thermometers; but the actual difference between the bulb readings is unrecorded. Yet the difference between the bulb readings is of great importance, for it indicates the cooling effect of the evaporative force of the air; and since evaporation is the chief means by which the body increases its thermolysis at high temperatures, information on this point is of great value. The effect of warm humidity on the heat loss of a moist body is just what we especially desire to know.

It might be thought that the cooling effect of evaporation would vary with evaporative force, and might be measured as the evaporative force and drying capacity of the air are measured, by shortage from saturation—the so-called "saturation deficit." It might be thought indeed that the cooling capacity and the drying capacity would vary *pari passu* and that each might be indicated by the same expression. But this is not so. The difference between the wet and dry bulb readings indicating cooling of the bulb does not correspond with the drying capacity of the air, and *vice versâ*.

Suppose a dry bulb to read 30° and a wet bulb to read 25°. Suppose another dry bulb to read 50° and a wet bulb 45°. In each case the difference in the readings is the same, *i.e.*, 5°; but in the first case the absolute humidity is about 14 grammes per cubic metre short of saturation, and in the second cases about 37 grammes per cubic metre short of saturation. The air in each case will have the same cooling capacity though in each case very different drying capacity.

In order, then, to have adequate information concerning the climatic qualities of air we require records of—

(*a*) Its absolute humidity—indicating its capacity for radiating and absorbing and conducting heat.

(*b*) The amount of vapour (stated either in grammes or in vapour tension) which it can still absorb—indicating its evaporate force and drying value.

(*c*) The difference between the wet and the dry bulb readings—indicating its cooling capacity for moist bodies.

At moderately low temperatures, where in damp weather conduction may cause undue thermolysis, the record of absolute humidity will be of greatest importance. At higher temperatures, where sufficient theromolysis depends chiefly on radiation and evaporative cooling, the records both of absolute humidity and of wet and dry bulb difference will be instructive.

The amount of vapour which the air *can* absorb is chiefly of interest if we have to consider its drying, not its thermolytic capacity—a question which will be discussed later in its connection with humidity and health.

Altitude and Humidity.—As we rise in height the air becomes colder and rarer and able to contain less moisture: its absolute humidity therefore decreases. Half the total water vapour of the atmosphere is below 2,000 m.; about three-quarters are below 4,000 m., and fully nine-tenths are below 6,500 m. On the other hand, its relative humidity shows no regular change with change of altitude, and is subject to constant and sudden fluctuations. Any saturation deficit has greater drying value than at low levels because of the diminished atmospheric pressure.

"Everything," writes Hann, in his "Handbook of Climatology, "dries much more rapidly at great altitudes. Dead animals are mummified without decaying. Thus we find that meat dried in the air is a national dish even in the lower Engadine at an elevation of 1,400-1,600 m. above sea-level. Further, perspiration evaporates rapidly; the skin is dry and parched, and thirst is increased."

Clouds.—Clouds are merely condensed water vapour and do not necessarily imply high relative or absolute humidity of the lower atmosphere. They act, however, like water vapour in controlling solar and terrestrial radiation, the general result varying with the latitude and season. Thus in the higher latitudes a low percentage of cloudiness reduces the winter temperature and increases the summer temperature, while in low latitudes a low percentage of cloudiness has exactly the opposite effect.

Rainfall.—The rainfall gives only a very general indication of the humidity of the atmosphere and a place with high rainfall may have low absolute and relative humidity, and *vice versâ.* It is a mistake to think that a rainy district is necessarily a damp district.

For instance Falmouth, with a rainfall of 43·56 inches, and Margate, with a rainfall of 23·31 inches, record an equal mean relative humidity, and though the absolute humidity of Falmouth is rather greater than the absolute humidity of Margate, yet the difference has no equivalence to the difference in rainfall.

Dampness depends more on the nature of the soil than on rainfall.

Dew.—Dew is a deposit of moisture from air cooled at night or morning beyond its saturation point. The principle of dew is illustrated by the condensation of breath on a cold mirror. Dew also bears no constant relationship to the humidity of the atmosphere, but a clear sky and a dry atmosphere favour its formation.

Mist.—"Mist," says Moore, "is in the strict sense of the term visible watery particles suspended in the atmosphere at or near the surface of the earth." In an applied sense it is coarser watery particles assuming the form of tiny raindrops and so floating in the air or falling to the ground. Air containing mist is obviously humid. The form of mist known as fog will be separately considered.

Humidity and Heat.—In the previous chapter we mentioned the fact that extremes of heat and cold are more trying when the air is humid. We will now discuss more fully the relationship between humidity and the temperature of the body.

We have seen that the body has great power of adaptation to changes of external temperature, and can maintain a constant temperature, even while the air may alter perhaps 200° F. Now the manner in which the temperature of the body is maintained constant, and the difficulties of such constancy depend chiefly on the humidity of the air.

From the germ-plasm onwards the living body constantly produces heat, and the result must be an elevation of temperature unless the heat be carried away as fast as produced. A man leading an active life produces in twenty-four hours about 3,000 kilogramme calories, *i.e.*, enough heat to raise 3,000 kilogrammes (about 6,600 lbs.) of water one degree Centigrade. At this rate he would reach boiling-point in about a day and a half. Thermolysis and thermogenesis must be equal. How, then, is heat carried away? The heat is carried away almost entirely by the air, and is carried away in three ways—by radiation, conduction, and evaporation—and the efficiency of this triplex process of cooling is greatly affected by water vapour. Let us look at the three ways by which heat is carried away and their relation to humidity.

Radiation.—Under ordinary circumstances 73 per cent. of the heat lost is radiated from the skin. To prevent too much radiation we wear clothes, and to permit more radiation we reduce our clothing. Moreover, when increased radiation is desirable, *e.g.*, in hot weather, or during violent exercise, the compensatory mechanism of the body sends more blood to the skin to be cooled, and when decreased radiation is desirable, *e.g.*, in cold weather, the same mechanism sends less blood to the skin. But the humidity of the air is a factor over which neither our tailor nor our nervous system has much control, and humid air—air of high absolute humidity—may prevent radiation just when radiation is most necessary. Thus in hot weather when it is difficult to keep cool, damp air may make it more difficult still.

Conduction.—Heat is conducted away to a certain extent by the air. When the air is dry and still very little heat is removed in this way, but if the air be moist with high absolute humidity and in movement, conduction may be a very potent instrument of refrigeration, and when the air is cold may lead, despite contracted cutaneous blood-vessels, to too great abstraction of heat.

Evaporation.—Evaporation both from the lungs and the skin is always an important factor in the loss of heat. We have already noted how much heat is carried away when water vaporises, and the same thing takes place when moisture evaporates from the skin and mucous surfaces. Evaporation, like conduction and radiation, is affected by humidity. As the saturation deficit of the air becomes smaller evaporation becomes less, and at high temperatures this diminution of evaporation may have serious effects.

Increased radiation and increased evaporation are the two expedients used by the body in order to increase loss of heat. The blood is sent in larger quantities to the surface that its heat may radiate away; and the sweat glands become more active and the skin becomes moist, in order that evaporation may be more effective. Both occurrences are of course physiological commonplaces, and both, as we see, are affected by humidity.

CHAPTER VII

HUMIDITY AND HEALTH

THE relationship of humidity to health is chiefly due to the relationship between humidity and thermolysis.

The relationship between humidity and thermolysis has already been discussed. We have seen how conduction, convection, evaporation, and radiation of heat are all largely determined by the water vapour in the air. Now, we know all the muscular and chemical actions of the body are associated with the production of heat, and can only take place so long as the temperature of the body does not rise too high or fall too low, and hence the influence of the humidity on thermolysis is of the greatest importance to the organism.

The physiological significance of the moisture in the air varies with the temperature of the air. At temperatures above a certain point, any considerable amount of moisture in the air which diminishes radiation tends to cause an accumulation of heat in the body, unless conduction and evaporation can compensate for the diminished radiation. As the temperature rises the compensatory loss of heat by evaporation becomes more and more necessary and ought to play a greater part in the regulation of the body temperature. Thus Rubner found in a fasting dog that the loss of heat by evaporation became proportionately greater as the external temperature increased.

External Temperature.	Total Heat produced.	Loss by Conduction and Radiation.	Loss by Evaporation.
° Centigrade.	Calories per Kilogramme.	Calories per Kilogramme.	Calories per Kilogramme.
7·6	83·5	71·7	11·8
15·0	63·0	49·0	14·0
20·0	53·5	37·3	16·2
25·0	54·2	37·3	16·9
30·0	56·2	30·0	26·2

Of course moisture in the air hinders evaporation as well as radiation, but luckily at high temperatures a good deal of moisture may be in the air without seriously hindering evaporation, and until the air is almost saturated increased loss of heat by evaporation can compensate for decreased loss by radiation, and no more serious result ensues than diminished vital activity as shown by diminished heat production. When, however, hot air above 88° becomes saturated, evaporation can no longer compensate for decrease in radiation, and the bodily temperature accordingly rises, and heat apoplexy may ensue. Recent experiments by Dr. Harvey Sutton in the Pathological Laboratory at Oxford have shown that heat apoplexy is always the result of combined heat and humidity, and that at a certain temperature—in his own case at a wet-bulb temperature of 95° F.—heat production becomes greater than heat loss and the temperature steadily increases. Dr. Haldane found that "with the air temperature at 131° and the wet bulb at 88° the body temperature remained the same after 2¼ hours. With the air temperature at 89° and the wet bulb at 89°, on the other hand, the body temperature rose nearly 3° in the same time, and with the air temperature at 94° and the wet bulb at 94° the body temperature rose 4° in two hours. The subject, who was the same in each of the experiments, was stripped to the waist and resting. With moderately hard work and a wet bulb temperature of 87° the temperature rose 4° in one hour." The first result of excessive humid heat is to cause drowsiness and languor, and this is succeeded, when the bodily temperature begins to rise, by irritability and wakefulness. It must be noticed that though evaporation is active in air at a high temperature, evaporation at high temperatures is not so cooling as at low; and that the only way to estimate the cooling value of evaporation is by noting the dry and wet bulb difference.

The amount of heat which may be abstracted by evaporation is very great. Thus Rubner calculates that a fat man out of doors in hot weather may lose 3,200 calories of heat by day—as much heat as is provided by an ordinary dietary. In hot, moist weather it is wise to eat little food since food—especially rich food—increases the production of heat in the body. Rubner states that by rich feeding heat production can be greatly and suddenly increased, even to the extent of 44 per cent.

In *dry* air at *high* temperatures radiation and evaporation are both more active, and thus there may be more heat production—more expenditure of energy, that is to say—without rise of bodily temperature. In the dry air of the African Karroo heat apoplexy is as rare as it is common in the moister air of the plains of India.

When we come to the consideration of humidity at lower temperatures we find somewhat changed conditions. At low temperatures air cannot hold sufficient moisture to interfere much with radiation, but there may be enough to favour conduction, and thus the general result of the moisture is to cool the body. But at low temperatures the body, under ordinary circumstances, does not require to be cooled, and the extra cooling caused by the moisture merely causes an unnecessary expenditure of food or tissue for the maintenance of the body's temperature, and may cause harm if the cooling outstrips the heat production. If the body sweats at low temperatures when the air is laden with moisture, the sweat does not evaporate gently as it would in cold, dry air, but lies on the surface of the skin and conducts away heat; and if a wind be blowing a great deal of heat may be lost in this way, and the body's temperature may fall below normal, and its resistance to disease be lowered. It has been proved by various experiments and by experience that a fall in the temperature of the body renders it more susceptible to certain germs.

But humidity not only affects the heat loss of the body, it also affects the water loss, and though water loss is chiefly important as heat loss, it also has its own physiological importance quite apart from its thermolytic relation. Protoplasm, the living matter of the body, contains about 80 per cent. water, and on the water in its composition its vital activity depends. Abstract the water and dry it up, and its vitality is arrested or destroyed. In man the loss of about 10 per cent. of his body water means death, and, as is well known, thirst kills much faster than starvation. Under average conditions of temperature and humidity the loss of water from the body per day is as follows:—

Under conditions of rest and hunger ...	1·25	per cent.	of body weight
Under conditions of rest and average diet	1·32	„	„
Under conditions of rest and rich diet	1·72	„	„
Hard work and average diet	2·91	„	„
Hard work and hot summer day ...	7·71	„	„

The amount of water lost per day, accordingly, varies within wide limits, and the variation is due chiefly to the heat and humidity of the surrounding air. Save the water passed off by the kidney and intestines, almost all the water lost is absorbed by the air from the lungs and skin. The greater the drying power of the air the more fluid can be evaporated from the skin. Now the drying power of the air, as we have seen, varies not with the relative humidity but with the deficit of moisture in the air. Air at 10° C. with a relative humidity of 36 per cent., and air at 30° C. with a relative humidity of 80 per cent., have each the same drying capacity because each has the same saturation deficit. It must not be thought, however, that the amount of fluid evaporated varies simply with the drying capacity of the air, for that is not so. Air at 10° C. with a relative humidity of 80 per cent. *can* evaporate as much moisture as air at 30° C. with a relative humidity of 80 per cent.; but in the case of the human body it will not usually do so, because at a temperature of 10° C. the sweat glands are not so active as at a temperature of 30° C. The activity of the sweat glands must be considered. Still air with equal drying capacity *permits* evaporation of the same amount of moisture, and in the case of air at the same temperature but with different drying capacity, the air with greater drying capacity can evaporate the more moisture from the skin and lungs. In the case of the lungs the temperature of the air is comparatively unimportant, since the inspired air is raised in the lungs to about body temperature and is saturated with moisture at that temperature. Dry air accordingly even when cold dries the mucous membranes of the nose, throat, and lungs, and is useful in catarrhal conditions. When the air is too dry, however, it may parch and crack the throat, and sore throats from this cause are common in dry climates, such as the climate of Davos.

As a rule the skin and lungs and kidneys act in reciprocity, and when one does more the other does less, but the drier the air the more the *total* amount of water excreted.

Rubner gives the following table to show the relation between dryness of the air and water output in the case of a dog:—

Temperature.	Relative Humidity of Air.	Water Output per Kilogramme per Diem.
° Centigrade.		
20·2	29·1	16·1
20·2	71·9	6·2
20·2	22·8	20·1
20·2	75·0	2·5
20·2	21·6	12·6

It will be noticed that the drier the air the greater the output of water.

At high temperatures the evaporation of water is, of course, essential to the removal of heat, but even apart from this useful function, the circulation of a certain amount of water is necessary for life and health, and it is possible that an increased circulation benefits the organism in various ways, and that stagnation of the water supply is injurious. The flushing of the tissues with large amounts of water must exercise a depurative influence; and, since a great part of the water in the body is in chemical combination, its flux also increases metabolism. Probably much of the harm attributed to damp and to cold is due to diminished water circulation, with consequent depression of metabolism or accumulation of toxins. Dry air quickens metabolism both through its cooling and drying capacity; damp air slows it by diminishing loss of water and (at high temperatures) loss of heat.

Subsoils.—The healthiness of dry subsoils, as compared with wet subsoils, is, no doubt, due to the fact that the damp subsoil increases the humidity of the air, and hence depresses general vitality, and the health of any town or district can be considerably increased by drainage of the subsoil. A damp subsoil was formerly thought to be the cause of consumption. In 1862 Dr. H. I. Bowditch formulated the "Law of Soil Moisture" as follows:—

1. A residence on or near a damp soil, whether that dampness be inherent in the soil itself or caused by percolation from adjacent ponds, rivers, meadows, marshes, or springy soils, is one of the primal causes of consumption in Massachusetts—probably in New England, and possibly in other portions of the globe.

2. Consumption can be checked in its career, and possibly—nay probably—prevented in some instances by attention to this law.

Later investigations by Dr. Gavin Milroy and Dr. G. Buchanan seemed to confirm this law, and Dr. Buchanan pointed out that there had been a remarkable decrease of consumption in towns in which the subsoil had been drained.

It is now, however, recognised that the relation between damp and damp soil and consumption is probably quite indirect, and due merely to the fact that damp depresses vitality in the ways already stated.

In a general way, then, damp air is depressing and enervating and dry air tonic and stimulating. In a general way, too, damp is dangerous and detrimental to the organism. But, on the other hand, *cold* damp is not quite so dangerous and detrimental as the public are apt to suppose, and it is most dangerous and detrimental to those who fear it most. The adaptation of the human body to variations in heat and humidity is very perfect, and by means of suitable clothing and food the range of its adaptability may be greatly increased; and a man may daily move in cold damp air and breathe cold damp air without suffering in his health to any appreciable extent.

He will, to some extent, suffer in his general vitality; he will not feel so fit, will not metabolise so rapidly or live so fully as in drier air; but, provided he is well fed and suitably clothed, his health will not be injured, and his body will easily supply heat enough to make up for the leakage through the damp air. When cold damp air is injurious, the victim is usually under-clad or underfed, or has been living an indoor life. Too little clothing is perhaps less harmful than too little food; for little clothing affects merely the *escape* of heat, while too little food affects its *production.* Almost more harmful than either, however, is indoor coddling. To the valetudinarian who sits over the fire in a hot room when it is damp; to the coddled child who is not allowed to go out when there is any moisture in the air, damp may be as dangerous as a Gatling gun. In the hot-house where the air is still and comparatively dry, and kept at an equable temperature, the skin, which is the regulator of combustion and of blood-distribution, has no stimuli and sends no messages either to the heat centres or to the vaso-motor centres: day after day it remains idle and useless, and, since the inside air is warm and dry, filled with a fair amount of blood. One fine day the hot-house organism ventures outside into the damp and cool air. The blood-vessels in his skin are dilated, the nerves of the skin, unaccustomed to any degree of damp and cold, are slow in causing vascular contraction, and the heat-centre, likewise unaccustomed to such an emergency, is slow in causing more combustion. Probably also, the individual, who has been living a sedentary, sheltered life, has been taking only enough food to make the little heat necessary in his warm environment, and has therefore little reserve fuel in his body. The result is that heat leaks away faster than it is produced, the body temperature falls below its normal, and the individual falls a prey to the first germ that he encounters, and thereupon shuts himself up again in his hot-house.

Three and a half centuries ago Dr. Caius, the founder of Gonville and Caius College, complained in his "Booke against the Sweating Sickness" of the system of coddling. "The olde manly hardness, stout courage, and painfulness of England, he writes, "is utterly driven awaye, in the stede whereof men now-a-dayes receive womanliness and become nice not able to withstand a blaste of winde or resiste a poore fish. . . . And children be so brought up that if they be not all day by the fire with a toste and butyre and in their furres they be straight sick."

Even when the clothes are wet the healthy body, leading an open-air life, and eating with an open-air appetite, can easily (unless in infancy or old age), provided the temperature be not very low and provided no wind be blowing, create enough heat to supply the leakage.

Damp Feet.—Damp feet are popularly considered particularly dangerous. No doubt damp feet *do* cause a chilling of the body which even the robust find it hard to resist. Yet this also may be due to coddling. Man in his natural condition must have his feet more often wet than any other part of his body; and children run about in wet grass without harm. The well-known French doctor Leroy, indeed, argued that the liking of children for bare feet proved that nature meant than to be left bare as long as possible.

In certain cases cold damp must be always injurious. In cases, for instance, where the vital forces are at a low ebb and where there is restricted capacity for making heat; in cases of kidney disease, and where hindrance of evaporation from the skin means extra work for the kidneys; in cases where there is a tendency to rheumatism or to rheumatic gout. But as a rule the danger of damp is exaggerated.

An interesting question is the influence between damp and the development of germs. Moulds, and germs generally, certainly grow best in the presence of moisture. Every one knows how boots and walls in a wet house become covered with mould.

It is very possible that damp may give additional vitality and virulence to germs floating in the air, and it is quite possible that the danger of damp sheets is partly bacterial and is not due entirely to thermolysis.

On the other hand, moisture prevents the rising of germs, and thus tends to diminish the germs in the air.

CHAPTER VIII

AIR AND SOLAR RADIATION. AIR AND ELECTRICITY. AIR AND RADIO-ACTIVITY.

THE influence of the atmosphere on solar radiation is much greater than is commonly supposed. All the solar rays that reach the earth penetrate the atmosphere, and in the course of their journey they are considerably thinned out and modified. Sunlight as it reaches us seems white, but when it leaves the sun it is probably blue, and it is the interception and scattering of the extra blue rays by the air—chiefly by the dust in the air—that gives blueness to the sky, and diffuses light. The importance of the dust in scattering and diffusing sunlight is often forgotten. Yet except for dust we should have a blue sun in a black sky. It is well known that a ray of light passing through a dustless dark box is unseen, and the city of Chicago is lighted by the dust in the air of its streets. The straight streets of Chicago "are lighted by a beam of electric light, which is shot like a cannon-ball along the centre of the street for a mile or two. The streets are thus satisfactorily lighted by the minute particles of dust reflecting some of the light from the beam in all directions on to the pavements and sides of the houses. If the air in the streets were free from dust, the streets would by this system of lighting be in absolute darkness." Cases of local interception of special rays by dust are seen in the colour effects produced by volcanic explosions. Whymper thus describes the colour effects of clouds of volcanic dust from Cotopaxi: "We saw a green sun, and smears of colour something like verdigris green high up in the sky, which changed to equally extreme blood-reds, or to coarse brick-reds, and then passed in an instant to the colour of tarnished copper, or shining brass. No words can convey the faintest idea of the impressive appearance of these strange colours in the sky—seen one moment and gone the next—resembling nothing to which they can properly be compared, and surpassing in vivid intensity the wildest effects of the most gorgeous sunsets."

Again, as we have seen, rays of radiant heat are intercepted both by carbon dioxide and by water vapour. It is very probable that sun *heat* would kill all living creatures, while selected sunlight—sunlight sifted by the atmosphere, is the sustainer and artificer of life.

Let us look at the matter in more detail. Sunlight, all that is left visible of it, when it reaches us, appears, as we have said, white; but nevertheless, as is well known, it really consists of coloured rays of different wave lengths and refrangibilities, and these can be bent apart from each other and shown in their true colours by means of a prism, such as the drops of water in a rainbow or by a spectrum "grating." When they are thus separated out, they are found to be coloured violet, indigo, blue, green, yellow, orange, and red. All the rays are ether waves, and all of them are capable of transformation into light, heat, chemical and electrical energy, or some combination of these, according to the molecular nature of the matter they meet. Under ordinary circumstances the most refrangible rays of the smallest wave-length at the violet end of the spectrum have most chemical effect; those in the middle, of medium refrangibility and wave-length, have the most lighting capacity, and those at the red end with the least refrangibility and wave-length have the most heating power. The rays at the violet end, for instance, which are often known as *actinic* rays, have the power of darkening photographic films, of causing the combination of chlorine and hydrogen, of oxidising oxalic acid, of turning the sunflower's head towards the sun, of killing microbes, &c.; the rays in the middle are seen in most forms of artifical light and have the power of stimulating the growth of plants, while the rays at the red end have the heating power exemplified in a red-hot poker. But what they do depends on what they meet: the short waves meeting the retina give a sensation of violet light, meeting certain salts of silver they darken them, and meeting a black coat they heat it. These are the *visible* rays of light; but beyond these, at the violet end, are invisible actinic rays known by their effects, and at the red end invisible rays of radiant heat, also known by their effects. With more sensitive retinæ we might, of course, see these rays as wonderful new colours, and it is quite possible that other animals and insects do see them, but to *our* retina, in its present state of development, they are invisible.

Such is selected solar radiation as it reaches us—a selection of luminous and calorific rays—and it is quite plain that the nature of the selection is of enormous vital importance. More heat and we might be roasted; more light and we might be blinded; more chemical energy and we might be slain like the microbes.

Let us glance for a moment at the manner and degree of selection, especially with regard to the constancy of the composition of the solar radiation that reaches us.

When we examine the colours of the visible solar spectrum we see black lines on it here and there, indicating the absorption of radiations. Most of these, as the spectroscope shows, represent radiations absorbed by the atmosphere of the sun; but others are certainly due to absorption by the atmosphere of the earth—some to absorption by even oxygen or nitrogen. Not only in the visible, but in the invisible spectrum do lacunæ appear: there are cold streaks in the infra-red, and non-actinic streaks in the ultra-violet, and some of those additional lacunæ are certainly due to atmospheric absorption. Further, even when the atmosphere does not absorb it may attenuate. The alteration and attenuation of *certain* rays of solar radiation by the air is a well-established fact; there is no doubt at all that heat is absorbed by carbon dioxide and by water vapour, and every cloud shows how light may be held or hindered; but the question of the absorption of chemical rays is not quite so simple, and the media of their absorption not quite so obvious. Are they absorbed, and if so, how? We have said that many of the blue rays are scattered by the dust in the sky, but still they are not checked altogether: most of them reach the earth as diffused light, and indeed we cannot consider that dust causes any marked variation in the actinic power of the sun. Nor has water or water vapour much effect on the chemical rays. Yet the actinic power of solar radiation certainly does vary, as every photographer knows. It might be thought that the actinic power would vary *pari passu* with variations in the heat or light; but this is not so. About the middle of last century Bunsen and Roscoe investigated this question of the atmospheric absorption of the chemical rays of the sun, and came to the conclusion that in passing through the atmosphere the rays lost about 66 per cent. of their chemical power. From a formula they suggested, Professor J. Sebelien has lately calculated that on Midsummer Day most actinic light is received between latitudes 20 and 50.

One of the most important recent investigations into the atmospheric relation to the chemical rays of the sun was made by E. Duclaux in 1894. In the course of these investigations, Duclaux estimated the chemical value of solar radiation by its power of oxidising oxalic acid, and showed that the value varied greatly, and varied quite independently of heat, light, and barometric pressure.

The following table shows the result of some experiments made at Fan in the Cantal:—

Date.	Barometric Pressure.	Maximum Temperature.	Oxidation of Oxalic Acid.	Condition of Sky.
			Per cent.	
Aug. 15	712	36·8°	21	Fine. Slight cirrus
,, 16	712	37·5	29	Fine
,, 17	710	37·5	34	,,
,, 18	710	37·5	32	,,
,, 19	705	35·9	32	East wind. Clear sky
,, 20	705	35·2	30	,, ,, ,, ,,
,, 21	705	30·0	24	Cirro - cumulus. Fresh weather
,, 22	705	25·0	24	Sky clouded in the morning
,, 23	705	22·0	22	,, ,, ,, ,, Cumulus
,, 24	710	30·0	27	Sky overcast
,, 25	710	25·0	25	Stormy weather. Rain at night
,, 26	705	30·0	30	Stormy weather. Cumulus
,, 27	700	29·0	26	,, ,, ,,

He continued his investigations in September and October and wrote thereafter: "These two months of uninterrupted observation prove already that the solar combustion passes through very different values within twenty-four hours. These changes are sometimes very sudden and exceed especially those of the thermometer, the barometer, and even those of the average brightness of the day. The actinometric effect does not show therefore that approximate constancy, which makes it relatively so easy to measure the other effects of solar radiation; it requires a very close and minute investigation."

It is impossible to discuss here Duclaux's numerous experiments, but we may quote the most important points in his summary of his results.

"6. The daily combustion (*i.e.*, oxidation due to the chemical rays of the sun), such as is measured with sterilised liquids, varies from one day to another much more than any other meteorological phenomenon, and while subject to the influence of what we call 'fine weather' and 'overcast weather,' it manifests very clearly other influences which are less visible.

"7. It shows also the influence of the seasons, and manifestly exhibits a maximum in spring.

"8. It is but feebly subject to the influence of altitude.

"9. On the other hand, it betrays so strongly the pressure of divers oxidisable essences or substances in the air, that we must consider local and daily variations as due to the atmosphere of actinic clouds which are discoverable only by the reduction and absorption which they produce in the chemical radiations of sunlight.

"10. The atmosphere of extreme northern regions is less absorbent than that of our temperate zones, and, consequently, at the same hours of the day, actinic radiation is more powerful, at the level of the soil, in the north than in the centre of Europe."

A comparison of the actinic value of light in central France and in Algiers may be of interest to show variation with latitude.

	Algiers.		Paris.	
	Actinic Oxidation. Per cent.	Weather.	Actinic Oxidation. Per cent.	Weather.
Aug. 27	9	Clouds afternoon, sun out 3 p.m.	29	Fine day
" 28	8	Sun all day	42	" "
" 29	7	" " "	41	" " , rather foggy
" 30	7	" " "	35	" " , some clouds
" 31	7	" " "	41	" " , some mist

We see here how fine days at Algiers and Paris mean very different amounts of actinic radiation.

Duclaux's estimates of the variations in actinic radiation and his explanation of them as due to the presence of more or less organic matter in the air may or may not be correct; both have since been impugned; but the fact remains that actinic radiation is affected in some way by the composition of the air and varies within very wide limits. The importance of this variation will be realised when we remember the varied part played by actinic rays in various chemical processes. Let us here capitulate a few of these. Violet and blue rays hasten the hatching of flies' eggs and of frogs' eggs; they sun-burn the skin; they kill many bacteria including the tubercle bacilli; they cause heliotropism; they combine chlorine and hydrogen into hydrochloric acid; they cause the oxidation of oxalic acid and other substances; they blacken certain silver salts; they cause a greater absorption of oxygen if they fall upon the eyes. These are a few of the known effects of the chemical rays, but there must be many connected with vital chemistry which are unknown, and in view of these effects and their variations we must recognise that the air as a filter of the sun bears a very important and only half-understood relation to life.

Nor is this all. We know something about certain vibrations of the ether which we call chemical rays, and luminous rays, and calorific rays, and we know something of the effect of the atmosphere in modifying and varying these, but there are many ether vibrations of which we know nothing, and these, too, are probably sifted by the atmosphere, and may reach us at different times in different proportions. Even, indeed, as the crops in the Northern zones outstrip the crops in the South of France; so, at certain times, may the activity of nations be stimulated or depressed by atmospheric variations affecting the composition of solar radiation. J. P. Langley considers that the master-key to some of the most important problems of meteorology "is to be found in the hitherto unrecognised study of the selective absorption of our atmosphere for heat"; and it may not be wrong to add that the master-key to some of the most important problems of life and health will be found in the hitherto unrecognised study of the selective absorption of our atmosphere for actinic rays.

The general effect of the sun on health and vitality is well known. One of Nansen's Polar party gives the following testimonial to the sun: "The last winter in the ice was simply awful. We had our fill of the darkness. We got sleepy and indifferent and shaky on our legs. We were not ill, but weak and dead beat, and the doctor was anxious about our brains. When the day came with the sun, it was like a resurrection for us all. We were electrified when we saw him. Nobody knows how fine the sun looks but those who have been six months in darkness. Then we came to strength again." In a paper of the day on which we write the following paragraph appears:—

"Up to the middle of April winter diseases were flourishing in true winter style; epidemics of various kinds kept the death-rate well up to the average, while the three diseases most affected by weather conditions—measles, bronchitis, and pneumonia—accounted for more than their usual number of victims.

"In the week ending April 17th, 1,606 people died in London, and the death-rate per thousand was 17·3. One month later, for the week ending May 15th, the deaths fell to 1,216 and the death-rate to 13·1 per thousand. Comparing these figures with the averages for the corresponding weeks of the past five years we find that the total number of deaths for the week was 198 below the average, and the death-rate for the last four weeks was more than 1½ per thousand below the mean rate in the corresponding periods of the previous five years. What cause, then, has been acting to make a typical spring month so abnormally healthful? There was no reason to suppose that this transitional period at the end of the winter proper would noticeably raise the level of health.

"The only explanation is that we have been under the sway of an influence so health-giving in itself that it could discount the fact that we are still wearing our winter bodies as well as our winter clothes in typical summer weather. The truth is that London people, like the trees and plants in the London parks, have been blooming luxuriously in an abnormal feast of sunshine. The sun is the master physician, and the credit is his."

Such is the general effect of the sun, and there is no doubt there are variations in its vital value with variations in the precise character of its radiations.

It must be recognised further that the atmosphere exercises a selective influence not only on solar but also on terrestrial radiation. The influence of the atmosphere in this latter respect has often been compared to the glass of a hot-house, since it permits the outward radiation of rays of short wave-length but prevents the escape of the longer waves of heat from the heated surface of the earth. These longer waves are absorbed chiefly by carbon dioxide and water vapour. This influence evidently plays an important part in the maintenance of atmospheric and terrestrial temperature.

Air and Electricity.—The question of electricity and the air is also a question of radiations of ether, and a question shrouded in much obscurity. It is probable that the air and earth are charged by electrons shot from the sun. The negative corpuscles are mostly caught in the atmosphere, charging it negatively, while the positive corpuscles mostly reach the earth charging it positively. Further, as Sir Oliver Lodge suggested, the negative corpuscles are probably drawn towards the Poles by the earth's magnetic field.

The electric potential varies considerably: it is highest in winter and lowest in summer, and shows diurnal variation; it is increased by winds, and is specially increased by the condensation of vapour. Vapour ascends charged with a certain amount of positive electricity; as it condenses its surface becomes smaller in proportion to its charge, and so the electrical tension is raised and may become so enormous that lightning will leap between clouds 10 miles apart. The electric potential increases as we ascend mountains, and on mountain-peaks many startling electrical phenomena are found. An observer on Pike's Peak (quoted by Leonard Hill in "Recent Researches in Physiology") describes how on one occasion "his hair stood erect, crackled, and the pricking sensation to the scalp was extremely painful. The peculiar electrical odour was strongly recognised To protect his head he put on his black felt hat, and returned to the roof. But a few seconds elapsed before he was fairly lifted off his feet by the electrical fluid piercing through the top of his hat, giving him such a sudden and fiery thrust that he nearly fell from the roof in his excitement. Instantly snatching the hat from his head, he observed a beam of light, as thick as a lead pencil, which seemed to pass through the hat, projecting to about an inch on either side, and which remained visible for several seconds. The top of his hat was at least 2 inches from his head when this fiery lance pierced him. When the fluid began to thrust its fiery tongues into other parts of his body he was spurred to a hasty, but brilliant retreat."

Mosso gives a similar account of an electrical storm on the Gnifetti Hut. "We were in the Gnifetti Hut (3,620 m.

on Monte Rosa) on the 7th of August when, towards evening, a storm rose. We noticed a party coming up across the glacier, and some of us went out to welcome the new-comers. I went down to the little hut to meet them. As I reached the door I heard a buzzing as of a number of wasps in the hut; but on looking there was nothing to be seen. I listened again and became aware that it was the corners of the hut which emitted a characteristic hissing sound, which I at once understood to be an electric phenomenon. As the weather was threatening and the flashes of lightning very close I took refuge under the arcade of the upper hut. Desiring to write some notes I took a knife to sharpen a lead pencil and noticed that the chips of wood stuck to the blade and to the fingertips. The peals of thunder were very near and the sky was so dark that one could not see to a distance of a hundred metres on the glacier. My companions, who returned shortly afterwards, told me that they had experienced the effects of the clectricity in a very remarkable manner. Bizzozero and Corporal Camozzi had repeatedly seen sparks darting round the axe and had felt pricks as from an electrical discharge. Corporal Jachini had twice taken off his cap thinking there must be pins in it which were pricking him; then he felt what seemed to be a heavy hailstorm pattering down on his head; he passed his hand over his crown and convinced himself there was nothing."

There can be little doubt that electric changes must exercise a very potent influence on health and vitality, but the influence is still obscure and mainly a matter of conjecture.

Air and Radio-activity.—Soon after the discovery of radium by the Curies, it was proved chiefly through the investigations of Elster and Geitel that the air and soil and certain mineral springs contained radio-active substances. Newly fallen rain and snow are also radio-active, and if they be evaporated their deposit is also radio-active. Air sucked from the soil by means of a pipe, or air shut up in underground cellars and caverns is specially radio-active, as is also the air on mountain-tops. The air in clear weather is more radio-active than in dull. The radio-active substance of the air is attracted by negatively charged bodies, and can be thus collected. Dr. Saaka, who examined the radio-activity of the air at Arosa (an Alpine health resort 6,000 feet high), found that it was three to five times as radio-active as air on the plain. He also pointed out that since the electrical tension on mountain heights was great there would be a tendency for the radio-active substances to be attracted to the body, and he suggested that mountain-sickness might be partly due to this fact. Experiments he made, however, were quite negative, and it is impossible to say with certainty whether a high degree of atmospheric radio-activity be beneficial or the reverse; but it is quite legitimate to *surmise* that the radio-activity of air, as well as the radio-activity of mineral springs, has curative properties, and that the stimulating effect of high Alpine air may be in some measure due to its great radio-activity. Certainly radio-active substances have important physiological, physical, and chemical effects. They ionise the air, rendering it a conductor of electricity; they cause fluorescence of certain chemical substances; they cause a sensation of light if they strike the eye; and if too active may cause destruction of living tissue. Substances so potent must have physiological significance.

CHAPTER IX

IMPURE AIR

UNDER this heading we will discuss only indoor air vitiated by respiration and skin emanations, and by the gases produced in the ordinary processes of heating and lighting rooms.

The most obvious result of ordinary vitiation is an increased proportion of carbon dioxide; and, to the general public, carbonic acid and impure air are almost synonymous. We have seen that in natural open air the percentage of carbon dioxide is very small and very constant—about ·03 per cent. Let us look now at its proportions in vitiated air.

M. G. H. Richards of the Massachusetts Institute of Technology made 5,000 analyses of the air of lecture-rooms and found often twice and sometimes three or four times the normal percentage of carbon dioxide. Pettenkofer found ·054 to ·070 per cent. in a fairly well-ventilated room; ·24 in an ill-ventilated sick-room; ·32 in a lecture-room; ·72 in a schoolroom; and as much as 2·1 in an Alpine stable where men and beasts were closely herded together.

From a table collated by C. Fox from articles by R. E. Weaver in the *Lancet* of July 6th, August 3rd, and August 17, 1872, we give the following figures:—

Nature of Workroom or Building (in Leicester).	Carbonic Acid per 100 of Air.
Boot and shoe finisher	·528
Framework knitter	·532
„ „	·408
Boot and shoe finisher	·460
Needlemaker	·287
Tailor's workshop	·306
Boot and shoe finisher	·259
Tailor's workshop	·217
Elastic web manufacturer	·211
Fancy hosier	·493
Boot and shoe riveter	·172
Riveting-room of boot manufacturer	·328
National School : science class-room	·241
„ „ boys' day-room	·116
„ „ girls' „	·164
„ „ boys' „	·309
„ „ girls' „	·204
Police-court : the Mayor's parlour	·120
„ the Town Hall	·098
Private house : sitting-room	·304
Newspaper office : compositors' room	·111
„ „ machine-room	·123
„ „ compositors' room	·149
Private house : 1 foot from floor of bedroom	·102
„ „ 1 foot from ceiling of same room	·150
„ „ 1 foot from floor of bedroom	·116
„ „ 1 foot from ceiling of same room	·164
National School : infants' room	·154
„ „ girls' room	·139
Private school	·120
„ „	·121
Elastic web manufactory : the lower or braid-room	·178
„ „ „ the upper or weaving-room	·328
Public library : reading-room	·206

Dr. Angus Smith in 1864 made analyses of air in close places in London, and though the following figures which we give are probably rather high they are approximately correct.

	Percentage of Carbon Dioxide.
Chancery Court, 7 feet from ground, closed doors	·193
Same, 3 feet from ground	·203
„ door wide open	·050
Strand Theatre, gallery, 10 p.m.	·101
Surrey Theatre, boxes, 10 p.m.	·111
„ „ „ 12 p.m.	·218
Olympic, 11.30 p.m.	·081
„ 11.55 p.m.	·101
Victoria Theatre, boxes, 10 p.m.	·126
Haymarket, dress circle, 11.30 p.m.	·075
Victoria Theatre, boxes	·076
City of London Theatre, pit, 11.15 p.m.	·252
Standard Theatre, pit, 11 p.m.	·320

Haldane and Osborne found in tailoring workshops from ·320 to ·532; in collar factories from ·133 to ·386; in dress-making workrooms from ·05 to ·266; in laundries from ·035 to ·257; in textile factories from ·032 to ·470; in humid textiles from ·035 to ·320; in cotton-spinning from ·035 to ·566. Dr. George Newman found in underground bakehouses ·120, ·175, ·169, ·136, as compared with ·049 in a bakehouse aboveground and ·045 in the open air. Dr. Scott Tebb found ·038 in the open streets, ·079 in the air of the platforms of the tube railway, and ·116 in the tube railway carriages.

These figures will show how largely the percentage of carbon dioxide in indoor air may exceed the percentage of carbon dioxide in normal pure air.

It must be noted that the carbon dioxide in a confined space may arise from several sources—from respiration, from burning coal, coke, peat, or wood, and from illuminants such as oil and coal gas—and that its significance varies with its source.

Carbon dioxide in indoor air derived from coal fires is usually very small in amount, since it with the other gases of combustion are heated and escape through the chimney; but very small quantities of carbon dioxide associated with carbon monoxide and sulphur compounds may be given to indoor air from this source.

From wood, coke, and peat fires very small quantities of carbon dioxide and sulphur compounds and monoxide may similarly be derived.

(In all cases carbon monoxide is a product of incomplete combustion, and it is formed plentifully in charcoal fires and in " slow combustion " fires.)

LONDON AIR—CARBONIC ACID—METROPOLITAN RAILWAY, NOVEMBER, 1869.

Date.	Place.	Time of Day.	Carbon Dioxide per cent.	Oxygen per cent
1869.				
Nov. 12	Tunnel between Gower Street and King's Cross stations : specimen taken at open window, first - class carriage	10 a.m.	0·150	20·66
" 12	Tunnel between Gower Street and King's Cross stations : specimen taken at open window, first - class carriage	7.30 p.m.	0·078	20·79
" 12	Tunnel, Praed Street : specimen taken at open window, second-class carriage	10.30 a.m.	—	20·71
" 15	Specimen taken during journey between Gower Street and King's Cross, first-class carriage, windows open	10.15 a.m.	0·338	20·66
" 15	Same	3 p.m.	0·155	20·70
" 15	Same	11 p.m.	0·150	20·74
	Average... ...	—	0·1452	20·70

A much more prolific source of carbon dioxide is found in the ordinary illuminants ; and the carbon dioxide so formed is much more likely to accumulate in the atmosphere.

The most common illuminant is coal gas. Coal gas is a mixture of gases—hydrogen, marsh gas, carbon monoxide mainly, with ethene, acetylene, benzene, nitrogen, oxygen, and carbon dioxide. A cubic foot of coal gas when completely burnt gives to the atmosphere about half a cubic foot of carbon dioxide and about 1·34 cubic feet of water vapour. An ordinary gas-jet burns about 6 cubic feet of gas per hour and produces about 3 cubic feet of carbon dioxide. The gas, however, is sometimes incompletely burnt, and products of incomplete combustion, such as carbon monoxide, ammonia compounds, and acetylene may also be given to the atmosphere. No carbon monoxide is given off "unless the flame is smoky or is rapidly cooled by something in contact with it."

Coal gas, in addition, contains sulphur, and its combustion therefore gives sulphur compounds to the atmosphere. The amount of sulphur in coal gas varies. In London coal gas there is usually not more than 12 grains in 100 cubic feet, while in provincial coal gas there may be as much as 40 grains in 100 cubic feet. The Metropolitan Gas Referees require all gas to be free from sulphuretted hydrogen, and to contain not more than 17 grains per 100 cubic feet of sulphur in other forms. Some authorities consider the sulphur compounds particularly prejudicial to health, and Notter and Firth make the following calculations:—

"For every 100 cubic feet of gas consumed containing 20 grains of sulphur, there would be ·032 cubic foot of sulphur dioxide formed, while with an impurer gas, containing 30 grains of sulphur per 100 cubic feet, the sulphur dioxide resulting would amount to ·048 cubic foot. Except under very unusual circumstances, ventilation would reduce these quantities, and according to Rideal, it is only when a room is so vitiated that the carbon dioxide has reached 50 volumes per 10,000 that the sulphur content of the air will exceed the limit of perception even with 40-grain gas. Our own observations indicate that with 35 grains of sulphur per 100 cubic feet of gas, there is a distinct taste of sulphur and irritation of the air passages when the sulphur dioxide reaches 17 volumes per 10,000."

A leakage of gas often causes sore throats owing to the sulphur compounds it contains.

Coal gas is often mixed with "producer gas, "water gas," or "carburetted gas," which contain large proportions of carbon monoxide, and thus increase the risk of carbon monoxide vitiation.

Paraffin and colza oil lamps, and tallow and sperm candles form more carbon dioxide per candle-power; but since they do not form sulphur compounds they vitiate the air less than gas. Kerosene, like coal gas, forms sulphur compounds.

Notter and Firth sum up the effect of carbonaceous illuminants as follows: "Elevation of temperature, addition of moisture, carbon monoxide, carbon dioxide, nitric and nitrous acid, compounds of ammonia and of sulphur, marsh gas, carbon particles, and acids of the fatty group."

Before leaving the subject of illuminants and air vitiation it may be well to point out that the vitiation of the air from the burning of coal gas varies considerably with the burner used. The following table given by Notter and Firth is instructive:—

	Quantity Consumed.	Candle-power.	Oxygen Removed.	Carbon Dioxide Produced.	Moisture Produced.	Heat Calories Produced.	Vitiation equal to Adults.
Tallow candles ...	2,200 grains	16	10·7 c. ft.	7·3 c. ft.	8·2 c. ft.	1,400	12·0
Sperm candles ...	1,740 "	16	9·6 "	6·5 "	6·5 "	1,137	11·0
Paraffin oil lamp ...	992 "	16	6·2 "	4·5 "	3·5 "	1,030	7·5
Kerosene oil lamp ...	909 "	16	5·9 "	4·1 "	3·3 "	1,030	7·0
Coal gas No. 5 Batswing burner ...	5·5 c. ft.	16	6·5 "	2·8 "	7·3 "	1,194	5·0
Coal gas, Argand burner	4·8 "	16	5·8 "	2·6 "	6·4 "	1,240	4·3
Coal gas, regenerative burner ...	3·2 "	32	3·6 "	1·7 "	4·2 "	760	2·8
Coal gas, Welsbach incandescent ...	3·5 "	50	4·1 "	1·8 "	4·7 "	763	3·0
Electric incandescent light...	0·3 lb. coal	16	0·0 "	0·0 "	0·0 "	37	0·0

Commenting on this table, they say: "Of the various forms of light derived from coal gas that yielded by the Welsbach or incandescent gas-burner stands out pre-eminently as the best. From the hygienic standpoint it is simply an ordinary Bunsen burner, over the flame of which is hung a network of incombustible material that is intensely luminous when raised to the temperature of flame. It is noticeable that the vitiation of air with carbon dioxide by one Welsbach burner, giving a 50-candle-power light and consuming 3·5 cubic feet of gas, is less than one-half that produced by an oil lamp of 16 candle-power and consuming a little over 2 oz. of oil. Further, 'while the increase of carbon dioxide per candle-power is only ·365 in the case of the incandescent or Welsbach light, it is 1·9 in the case of the Argand burners, 2·86 in the batswing, and 1·6 in oil lamps'; and the increase of temperature in a room with a Welsbach burner per candle-power is 'only ·116°, compared with the Argand ·59°, the batswing ·807°, and oil lamps ·468°.'"

A similarly instructive table is given by Haldane and Osborne in their Departmental Report on Ventilation. It must be specially noted that a flaring gas burner is not only wasteful, since it implies the escape of unburnt gas, but also harmful to health, since the unburnt gas vitiates the air. Care should therefore always be taken that there be a suitable pressure maintained between tap and burner, so that the gas may burn steadily without jumping and flaring of the flame.

Description of Burner.	Pressure in Inches of Water between Tap and Burner.	Consumption of Gas in Cubic Feet per Hour.	Light in Candles.	Light in Candles per Cubic Foot of Gas Burned.
Standard “London Argand”...	—	4·86	16·0	3·29
“Union” or “Fishtail” No. 8	1·7*	12·6	22·6	1·79
	1·4	11·2	24·0	2·14
	0·8	8·2	23·7	2·87
	0·4	5·6	17·5	3·12
	0·2†	3·15	9·1	2·89
“Union” No. 6	1·8*	10·0	12·8	1·28
	1·2	8·1	15·7	1·94
	0·8	6·25	14·3	2·29
	0·4	4·15	10·0	2·41
“Union” No. 4	2·0	9·4	6·1	0·65
	1·7	8·3	8·9	1·07
	1·2	6·7	9·4	1·40
	0·8	5·1	8·4	1·65
	0·4	3·6	6·8	1·89
“Union” No. 2	1·8	5·5	3·45	0·63
	1·2	4·5	3·45	0·77
	0·8	3·8	3·5	0·92
	0·4	2·4	2·8	1·17
	0·2†	1·45	1·9	1·34
“Union” No. 0	1·9	4·5	1·6	0·36
	1·2	3·5	1·7	0·49
	0·8	2·7	1·6	0·59
	0·4	1·55	1·3	0·84
	0·2†	0·97	0·88	0·91
“Batswing economiser” No. 7, placed on “Union” No. 0...	1·0	4·5	14·7	3·27
	1·2	3·5	11·0	2·97
	0·2†	0·97	2·1	2·16
“Union economiser” No. 6, placed on “Union” No. 2...	2·3	5·9	13·9	2·36
	1·8	5·25	12·4	2·36
Common iron batswing, no number (irregular flame) ...	0·6*	16·0	37·3	2·33
	0·4	13·0	37·7	2·90
	0·3	10·0	34·2	3·26
	0·2	7·6	25·3	3·33
	0·15	5·5	17·8	3·24
‘Batswing” No. 7	1·1	12·0	26·2	2·18
	0·7	9·5	22·9	2·41
	0·4	6·1	18·2	2·98
Cone-top burner, no number	1·8	6·8	21·6	3·18
	1·2	4·55	14·5	3·19
	0·5†	1·8	4·55	2·53
Cone-top governor burner ...	2·0	4·95	16·05	3·24
	1·0	4·8	15·65	3·26
Average of incandescent mantles :—				
After 1 hour's use ...	—	4·25	73·9	17·4
„ 24 „ ...	—	4·25	70·3	16·5
„ 100 „ ...	—	4·25	62·2	14·6
„ 300 „ ...	—	4·25	56·4	13·3
„ 600 „ ...	—	4·25	53·8	12·7

* Flaring. † Small Flame.

The gases produced by illuminants are heated, and rise to the roof, as the following table, also from Haldane and Osborne's Departmental Report, will show:—

	Volumes of Carbon Dioxide per 10,000.			Temperature °C.	
	At 1 foot from Floor.	At 4 feet from Floor.	At 1 foot from Roof.	At 4 feet from Floor.	At 1 foot from Roof.
Before gas lit ...	—	2·9	—	12·5°	12·5°
13 min. after gas lit	—	—	13·8	—	—
18 " "	—	4·8	—	—	—
24 " "	7·5	—	—	—	—
30 " "	—	—	20·2	—	—
36 " "	—	9·0	—	—	—
44 " "	12·7	—	—	—	—
53 " "	—	13·9	—	—	—
59 " "	—	—	27·7	—	—
64 " "	16·5	—	—	—	—
68 " "	—	17·4	—	—	—
90 " "	—	—	34·3	—	—
96 " "	—	19·4	—	—	—
102 " "	19·6	—	—	15·0	18·8
140 " "	—	—	39·0	—	—
144 " "	—	25·8	—	—	—
148 " "	24·8	—	—	15·4	19·4

"In calculating," then, "the probable effect of combustion of gas on the purity of air in a room it is evidently necessary to consider to what extent the arrangements for ventilation permit the heated air from gas-jets to escape without vitiating the air at the breathing level."

So much, then, for carbon dioxide and associated impurities derived from carbonaceous fuel. Let us look, now, at the carbon dioxide produced by respiration.

The carbon dioxide produced by respiration varies with the vitality, size, and activity of the individual breathing. Exercise especially affects the amount generated, and during violent exercise almost ten times as much carbon dioxide may be discharged as during sleep. Diet, temperature, &c., also cause variation. On the average, during complete rest a man discharges about ·6 of a cubic foot of carbon dioxide per hour, and a woman about ·4 of a cubic foot. During hours of ordinary activity a man produces 1·1 cubic feet of the gas per hour, or, in round numbers, 1 cubic foot per hour. Therefore, so far as carbonic acid is concerned, a man vitiates the air much less than a gas-jet.

On the other hand, respiratory carbon dioxide indicates impurities probably more serious than those associated with the carbon dioxide of gas. The carbon dioxide of gas indicates sulphur, and moisture, and perhaps a trace of carbon monoxide, or ammonia, or acetylene; while the carbon dioxide produced by breath indicates vitiation by organic matter contained in the breath, and by emanations and particles from the skin.

From the lungs and skins of animals are given off not only carbon dioxide and water vapour, but also organic matter and waste products of various kinds which help to vitiate the air. One cannot mention any definite organic toxin of the breath, and its toxicology is still in dispute; but sweat contains a number of recognised constituents—"salt, lactate, butyrate, and acetate of ammonium, calcic phosphate, ferric oxide, volatile fatty acids, sometimes valerianic and caproic acids, and sometimes leucin." The skin thus gives to the air salts of various kinds, organic and inorganic, fatty acids, ammonia, and also particles of epidermis; and no doubt it also gives off other unknown substances.

Now to come to the question—Is air, vitiated with such products as we have mentioned, unwholesome?

In extreme cases there can be no doubt about the answer, for Death himself has several times answered the question most dramatically. After the battle of Austerlitz, for instance, 300 Austrian prisoners were shut into a small prison and 260 were killed by the impure air. In the tragedy known as the Black Hole of Calcutta, January 18, 1756, 146 adults were shut into a room only 18 feet square and with only two small windows to ventilate it. They were shut in at 8 p.m., and within an hour some were dead, and when the door was opened at 6.20 next morning only 23 were left alive. One of the survivors gives the following description of the horrors of the night: "At this period so strong a flavour came from the prison that I was not able to turn my head that way for more than a few seconds at a time. Everybody except those at the windows now grew outrageous and many delirious. By eleven o'clock greater numbers were dead or dying, and those living were in an outrageous delirium and others quite ungovernable. A steam now arose from the living and the dead which most awfully affected those who were still alive. At six o'clock next morning it came to the ears of the Indian governor the havoc death had made in this fearful place, and he ordered their release. At 6.20 there came out of this living grave 23 *half-dead creatures*, being all that remained of the 146 souls who had entered the Black Hole prison, and these were in such a condition that it seemed very doubtful whether they would see the morning of another day. Many of the survivors developed putrid fever and boils. The remaining 23 were poisoned by exhalations from their own lungs and bodies."

An almost equally terrible tragedy took place nearer home, on the steamer *Londonderry* going between Sligo and Liverpool. The tragedy is thus described by G. Henry Lewes ("Physiology of Common Life"):—

"On Friday December 2, 1848, she left for Liverpool, with two hundred passengers on board, mostly emigrants. Stormy weather came on, and the captain ordered every one to go below. The cabin for the steerage passengers was only 18 feet long, 11 feet wide, and 7 feet high. Into this small space the passengers were crowded; they would only have suffered inconvenience if the hatches had been left open; but the captain ordered these to be closed, and —for some reason not explained—he ordered a tarpaulin to be thrown over the entrance to the cabin, and fastened down. The wretched passengers were now condemned to breathe over and over again the same air. This soon become intolerable. Then occurred a horrible scene of frenzy and violence, amid the groans of the expiring and the curses of the more robust; this was stopped only by one of the men contriving to force his way on deck, and to alarm the mate, who was called to a fearful spectacle: seventy-two were already dead, and many were dying; their bodies were convulsed, the blood starting from their eyes, nostrils, and ears."

"These," reports the *Times* of December 7th, "lay in heaps; the living, the dying, and the dead one frightful mass of mingled agony and death—a spectacle enough to appal the stoutest heart."

In the days of slave-trading, when the wretched niggers were packed like sardines between decks, many similar holocausts occurred.

These are, of course, very extreme cases. Such foul air is never breathed under ordinary circumstances; and the question may still be asked, Does such vitiated air as is *ordinarily* breathed in human habitations cause ill-health apart from the infectious germs or infectious material it may contain; and if it does cause ill-health, in what manner? It is, of course, almost universally believed nowadays that indoor air, rendered impure by respiration, and combustion, is harmful to the health. To bad air we attribute much of the anæmia, the pallor, the neurasthenia, the general ill-health of slum-dwellers and factory workers and most persons engaged in sedentary indoor occupations. Every one knows, too, how a close, stuffy atmosphere produces headache, loss of appetite, and even faintness.

And yet when we begin to look into the matter we find it difficult to prove the bad air guilty, and we find it more difficult still to discover how it works evil. The air of ill-ventilated indoor inhabited places contains, as we have seen, more than a normal amount of dust, of moisture, of organised and inorganised organic matter and of carbon dioxide. Now, putting germs out of the question for the moment, are any of these constituents in excess detrimental to the health? Ordinary indoor dust is not particularly pernicious, nor is moisture, and so suspicion naturally falls either on the excess of carbonic acid or on the excess of organic matter expired in the breath, and exhaled from the skin.

Now, as we have seen, the carbon dioxide seldom arises above 50 volumes per 10,000, and since it requires about six times as much to disturb the breathing or produce any abnormal physiological effect, many investigators have leaned to the opinion that impure air must contain some volatile organic toxin prejudicial to the health, and many attempts have been made to find the pernicious toxin.

In 1879 Seegen and Nowak thought that they had proved the presence of poisonous organic matter in expired breath; and in 1887 Brown Séquard and d'Arsonval reported that they had caused the death of animals by injecting beneath their skins the condensed moisture of the breath. They believed the poison to be a ptomaine not unlike Brieger's ptomaine. In the following year, however, Dastre and Loye, and Von Hofmann-Wellenhof controverted Brown Séquard's and d'Arsonval's experiments.

Dastre and Loye's experiments were as follows:—

Injected	5 rabbits	with	33 to 75 c.c.	of fluid	—result	negative.
„	2 guinea-pigs	„	5 to 7 c.c.	„	„	„
„	2 dogs	„	30 to 53 c.c.	„	„	„
„	2 rabbits	„	50 to 90 c.c.	„	—died.	
„	young dog	„	30 of water	„	„	

They considered that the deaths were due simply to excess of fluid injected and not to any toxin.

In 1889 Brown Séquard and d'Arsonval made further experiments to prove the toxicity of expired air. They put rabbits in a row of metallic cages which were connected in series with each other by rubber tubing in such a way that the final cages only obtained air as aspirated through the others. The air, however, was cleared of excess of carbon dioxide by being drawn through soda-lime solution, and the air between the penultimate and last cage was also drawn through sulphuric acid to clear it of any organic matter. The result was that rabbits in the penultimate cage which breathed air vitiated by organic matter emanating from the rabbits in the preceding cages, died, while rabbits in the last cage which breathed air filtered through the sulphuric acid lived.

In 1890 Lehman and Jessen made a careful analysis of the condensed fluid of breath, and found it a colourless, odourless fluid, of neutral reaction. It contained a trace of hydrochloric acid, and a very small amount of ammonium chloride which seemed to be a product of decayed teeth and never amounted to more than 10 milligrammes in a litre. No alkaloid could be detected. In 1892 Merkel confirmed Brown Séquard's results with the cages.

In the same year Beu tried to explain away the cage experiments by suggesting that the good effect of the sulphuric acid was really due to the removal of moisture from the air. And about the same time also Rauer, Lubbert and Peters, Haldane and Lorrain Smith made experiments, with negative results.

Nevertheless, in 1894 Brown Séquard and d'Arsonval maintained their original thesis that expired air contains volatile organic poison. In 1895 Dr. Sivierato "collected the aqueous vapour of the breath of persons suffering from diseases of respiration both with and without fever, of persons with no respiratory disease but with fever, and of persons in health, and injected it into rabbits. That from those with respiratory diseases produced fever and diminished reflexes lasting three to six days; that from cases of fever with no respiratory diseases caused little or no disturbance, and that from persons in health produced no result whatever.

To settle the moot question investigations were undertaken on behalf of the Smithsonian Institute of Washington by J. S. Billings, S. W. Mitchell, and D. H. Bergey, and they reported as follows:—

"I. The results obtained in this research indicate that in the air expired by healthy mice, sparrows, rabbits, guinea-pigs, or men there is no peculiar organic matter which is poisonous to the animals mentioned (excluding man) or which tends to produce in these animals any special form of disease. The injurious effects of such air observed appeared to be due entirely to the diminution of oxygen or the increase of carbonic acid, or to a combination of these two factors. They also make it very improbable that the minute quantity of organic matter contained in the air expired from human lungs has any deleterious influence upon men who inhale it in ordinary rooms, and, hence, it is probably unnecessary to take this factor into account in providing for the ventilation of such rooms.

"II. In ordinary quiet respiration no bacteria, epithelial scales or particles of dead tissue are contained in the expired air. In the act of coughing or sneezing, such organisms or particles may probably be thrown out.

"III. The minute quantity of ammonia or of combined nitrogen, or other oxidisable matters found in the condensed moisture of human breath appears to be largely due to products of the decomposition of organic matter which is constantly going on in the mouth and pharynx. This is shown by the effects of cleansing the mouth and teeth upon the amount of such matters in the condensed moisture of the breath, and also by the differences in this respect between the air exhaled through a tracheal fistula and that expired in the usual way.

"IV. The air in an inhabited room, such as the hospital ward in which such experiments were made, is contaminated by many sources besides the expired air of the occupants, and the most important of these contaminations are in the form of minute particles or dusts."

The evidence at present, therefore, is against organic toxins, and the opinion at present held is that the combined heat and moisture of ill-ventilated rooms is the main cause of their pernicious influence on the health, and it has been shown that when the air is kept cool and dry large amounts of carbon dioxide can be tolerated without discomfort.

Personally we venture to suggest that the question is still open, and that the experiments made have not quite reproduced natural conditions.

In the first place, the experiments seem to have been of much too short duration. In the second place, the experiments have been made chiefly on such animals as rabbits which presumably are accustomed to breathe vitiated air in their burrows, which have much greater respiratory exchange than man, and whose food and skin emanations must be of a very different nature from those of man. In the third place, the air has not contained the dust and germs that vitiated air usually contains.

Air containing merely the carbon dioxide and moisture usually contained in vitiated air will not produce the effect of vitiated air, and vitiated air therefore must contain an additional constituent. This additional constituent, though undetected by chemists, is probably detected by the nose, for it is well known that air is oppressive and harmful not so much in proportion to the amount of carbon dioxide and moisture it contains, as in proportion to its smelliness. The relationship between organic effluvia and the healthful performance of physiological functions is so close that a bad smell may cause nausea or faintness. The very fact that the nose is so sensitive to such odours would seem to suggest their harmfulness.

What the nature of these malodorous substances may be is obscure, but they are probably manifold in character, and we suggest that they originate chiefly from the skin. De Chaumot, examining the air of barracks, stated that an unpleasant smell became perceptible as soon as the carbonic acid was 2 volumes per 10,000 above that in the outside air, and Haldane and Osborne remark that "in rooms where the standard of personal cleanliness is higher the excess may, in our experience, considerably exceed 2 volumes without any unpleasant smell being perceptible."

When one considers what an important eliminating organ the skin is, and its vicarious relationship to the kidneys, one must realise that it may contribute a considerable variety of volatile substances to the air, and that even the microbic decomposition of the sweat may result in divers products, according to the health and cleanliness of the individual. One knows that the odour of a dog's skin becomes unpleasant if it have too much meat in its diet; one knows that a negro has a different odour from a white man; one knows that such diseases as consumption, cancer, and rhuematic fever give the patient characteristic odours, and one must therefore admit that the emanations from the skin vary considerably, and may be harmful in one case and not in another. Parkes and Kenwood suggest that the action of odoriferous volatile substances on the olfactory nerves "may ultimately induce through the central nervous system alterations in respiration, circulation and nutrition, which are inconsistent with the maintenance of good health." What may be the nature of the emanations in cases of skin disease we cannot say, but they can hardly be healthy to breathe. It will be remembered that in the account we have quoted of the Black Hole of Calcutta, it is stated that "many of the survivors developed putrid fever and boils," and these ailments could hardly be the result of excess of carbon dioxide and moisture.

Arloing made a watery extract of the underclothes of a man who had sweated much during a long evening of dancing, and injected the extract into dogs and rabbits, and found that they showed evidence of toxic influences and died, and though other experiments have not confirmed his results, yet they have not been made under natural conditions.

It must be noted that chronic overcrowding and bad ventilation are most common among the diseased and dirty. The rabbits in the cage are hardly fair representatives of men and women, unwashed and diseased, wearing undergarments saturated with decomposing organic material, and living in dirty houses amid dust and germs.

There seems a fair presumption, then, that the skin is the chief source of poison in so-called vitiated air; but it is very possible that in disease the expired air may be altered in character and contain new organic matter, even as it has been shown by Formanek that decayed teeth are the chief source of ammonium chloride in the breath.

The relationship between the effects of vitiated air and its microbic contents has yet to be demonstrated. As we have shown in other chapters, the microbes in inside air are more numerous than in outside air, and increase with deficient ventilation. We have likewise shown how numerous microbes may be, and St. Clair Thomson has calculated that in London it must be quite common to breathe about 300,000 microbes a day. Now the question has still to be answered as to the effects of these microbes on the health.

We know that most of the microbes we inhale are destroyed in the upper air-passages, and are probably removed by phagocytes. We know, also, that in certain cases certain microbes succeed in gaining a footing and cause certain diseases. But it seems hardly reasonable to make a hard-and-fast division and to divide microbes into simply two classes—harmless and harmful. It is surely very likely that many microbes which are destroyed and which cause no symptoms of disease may yet be detrimental to the health; and it is surely very likely that the pernicious effect of vitiated air may be partly due to the excess of microbes it contains. Where there are many microbes it would be very extraordinary if none of them were in any degree harmful. It must be remembered, too, that these microbes are inhabitants of the air, and must to a certain extent vitiate it by *their* life processes.

Another point to be noticed with regard to vitiated air is that it is usually stagnant air. Now stagnant air is air that never occurs under natural conditions, and it implies an absence of skin reflexes which are important stimuli to normal metabolism. In the moist, warm, still air the cutaneous vessels remain in a relaxed atonic condition, and the disused vaso-motor centres grow forgetful of their reflex function.

It seems probable, then, that vitiated air causes discomfort and disturbance of the health in various ways; it contains an excess of carbonic acid; it is moist, warm, stagnant; and in many cases laden with bacteria, bacterial products, and effete emanations from the skin and lungs.

Let us glance for a moment at the effect of the excess of carbon dioxide and the diminution of oxygen in vitiated air. Has this variation no vicious effect?

In normal air there are 3 or 4 volumes of carbon dioxide in 10,000; but the air we actually *breathe*—the air in the alveoli of the lungs—contains 5 or 6 per cent. of carbon dioxide. Even though the proportion of carbon dioxide in the air increase considerably, the proportion of carbon dioxide in the alveoli of the lungs is kept constant by a compensatory quickening and deepening of the breathing. The most vitiated air examined by Haldane and Osborne contained only 56 or 57 volumes of carbon dioxide, and this would have no effect on the composition of the air in the alveoli.

It must not, however, be too readily assumed that an increase in the amount of carbon dioxide in the air is quite harmless. Any one who compares his power of mental work in a pure and in a carbonic-acid-laden atmosphere, even if the latter be dry and cool, will find in the latter a considerable diminution, showing that at least nerve metabolism is affected. Nature has taken such particular pains to supply the central nervous system with particularly pure, well-oxidised blood, that it is probable a very small oxidative difference may have considerable consequences. Now, the more carbon dioxide and the more moisture there are in the air, the less oxygen will there be to any given cubic volume of air; and if the air be in addition heated there will be further diminution of oxygen. It is true that the diminution produces no *obvious* objective physiological effect, and that the increased ventilation can compensate for the diminution; still, nature is economical of effort, and if she find that more labour has to be expended to keep the carbon dioxide pressure in the alveoli low and the oxygen pressure high she will almost certainly reduce her standard and rate of living, will put less carbon dioxide into the blood and take less oxygen from it; and accordingly the fire of life will burn low, and there will be less power of work and less resistance to disease.

It may be contended that the human constitution becomes in time accustomed to vitiated air, and that much of the ill-health ascribed to bad air is really due to other circumstances, such as poor feeding and depressing surroundings, but the difference in health between country poor and city poor, and the improvement in health which always follows removal from impure to pure air, is sufficient answer to such a contention. Even an open window may work wonders; and the improvement in appetite, nerve-vigour, blood-quality, and muscular tone which follows open-air treatment, even in the rich and well-fed, shows the paramount importance of fresh air. Can it be doubted, when even a whiff of fresh air may revive a fainting patient? There is a foolish idea prevalent that night air is not pure air, and accordingly a considerable proportion of mankind shut themselves into the *pure* air of their bedrooms, and waken in an atmosphere almost as foul as the Black Hole of Calcutta. This false idea probably originated in a erroneous interpretation of malaria. It was found that those going out after sundown were much more liable to attacks of malaria, and since malaria (as the etymology of the word suggests) was supposed to be due to bad air, night air was naturally supposed to be particularly bad. Now we know that the increased liability to contract malaria after sun-down is due not to bad air at that time, but due to the fact that the malaria mosquitoes begin to fly abroad at that time. Probably the prejudice against ground-floor bedrooms arose in much the same manner, since mosquitoes are not high flyers and are more likely to attack those sleeping on the lower floors.

As a matter of fact night air is purer than day air, since very few fires are burning to pollute the air: it also contains fewer germs and more ozone and electricity. On the other hand, it is of course colder and damper, especially at the time the morning dew is deposited.

CHAPTER X

POLLUTED AIR: *SMOKE*, *FOG*, GASES IN MINES, GROUND AIR, SEWER AIR, OFFENSIVE GASES FROM TRADES

SMOKE.—Smoke is a product of combustion, and consists of a mixture of gases containing solid particles. When coal, coal gas, wood, paraffin, petroleum, and other carbonaceous matters are burnt, the gas consists chiefly of carbon dioxide and solid particles of unburnt carbon, besides, of course, the gases of the air. Angus Smith gives the following analysis of smoke from a common house-fire:—

Smoke from a Common House-fire.

Source of Gas.	Carbon Dioxide.	Carbon Monoxide.	Oxygen.	Nitrogen.
Gas from chimney 4 feet above the fireplace	0·35	—	16·93	80·02
	1·65	0·38	19·29	78·68
Gas from the middle of a good fire.	19·46	0·09	—	80·45
	20·90	0·10	—	79·00
A great mass of coal over the fire, the gas taken from below the glowing mass...	17·50	—	0·6	80·04
	17·44	—	0·39	82·17
A heap of glowing coal, gas taken close to spot where carbonic oxide was burning	15·43	3·49	0·96	80·12
	18·17	2·48	—	79·35
Gas from the clear fire below ...	16·10	—	4·95	78·95
Gas from the same fire at the upper part, 1 inch below the surface ...	17·21	—	4·25	78·54
	18·20	0·99	—	78·21

The solid particles, we say, consist of unburnt carbon; but carbon is quite combustible, and with a sufficient supply of air or oxygen all the carbon in such carbonaceous substances as we have mentioned, might be burned away into carbon dioxide. Under ordinary conditions of imperfect combustion, however, some carbon is left unburnt. The small quantities of unburnt carbon thus given to the atmosphere mount up to a very big sum. From measurement of the soot which had accumulated upon the greenhouse at Kew, Sir W. Thistleton Dyer calculated that there was a deposit of carbonaceous matter from the London air during fog at the rate of six tons per week to the square mile. Dr. W. N. Shaw estimates that London gives to the atmosphere every day about seven million tons of smoky air, containing over four hundred tons of soot, and he calculates that smoke deprives London of about one-sixth of its possible sunlight and daylight in summer, and of about one-half of its possible sunlight and daylight in winter. In other towns things are equally bad—"Comes a vapour from the margin, blackening over heath and holt." Primrose calculates that in Glasgow more than two and a half tons of soot fall annually on each acre. Dr. J. B. Cohen calculates that in Leeds about twenty tons of carbonaceous matter is thrown into the air daily, and that the daily downfall of carbonaceous matter is at least half a ton to the square mile. He calculates too that the smoke of Leeds deprives it of about 30 or 40 per cent. of its possible sunlight yearly. Well might Ruskin lament: "In that half of the permitted life of man I have seen strange evil brought upon every scene that I best loved or tried to make beloved by others. The light that once flushed those pale summits with its rose at dawn, and purple at sunset, is now umbered and faint; the air which once inlaid the clefts of all the golden crags with azure, is now defiled with languid coils of smoke, belched from worse than volcanic fires." . . . The following interesting table prepared by the Manchester Air Analysis Committee is given by Dr. Cohen :—

Deposits on Holly or Aucuba Leaves collected December 14 to 16, 1891. (Milligrams per Square Metre of Leaf Surface.)

Locality.	Solid Matter.	Sulphuric Acid.
Alexandra Park	131	7·2
Owens College	315	10·4
Hulme	420	26·0
Harpurhey	443	19·0
Infirmary	728	27·5
Albert Square...	833	24·2

An analysis of soot collected in February, 1891, from the roofs of glass houses at Kew and Chelsea gave the following result :—

Substances.	Chelsea.	Kew.
	Per cent.	Per cent.
Carbon	39·0	42·5
Hydrocarbons	12·3	4·8
Organic bases (pyridines, &c.)	2·0	—
Sulphuric acid	4·3	4·0
Hydrochloric acid	1·4	0·8
Ammonia	1·4	1·1
Metallic iron and magnetic oxide of iron ...	2·6	—
Mineral matter (chiefly silica and ferric oxide)	31·2	41·5
Water not determined (say difference)... ...	5·8	5·3

It is the large manufacturing chimneys that are the chief offenders. Hear what the well-known writer Evelyn had to say on the subject about two hundred and fifty years ago: " For, as we have said, the culinary fires (and which charking would greatly reform) contribute little or nothing to these foul-mouth'd issues, and curls of smoke which (as the poet has it) do *cœlum subtexare fumo* and draw a sable curtain over heaven. Let any man observe it, upon a Sunday, or such time as these spiracles cease, that the fires are generally extinguished, and he shall sensibly conclude by the clearness of the sky and universal serenity of the air about it, that all the chimneys in London do not darken and poison it so much as one or two of those tunnels of smoke, and that, because the most imperceptible transpirations, which they send forth, are ventilated, and dispersed with the least breath which is stirring. Whereas the columns and clouds of smoke which are belched forth from the sooty throats of those works are so thick and plentiful that, rushing out with great impetuosity, they are capable to resist the fiercest winds, and being surcharged with a fuliginous body, fall down upon the city before they can be dissipated, as the more thin and weak is, so as two or three of these fumid vortices are able to whirl it about the whole city, rendering it in a few moments like the picture of Troy sacked by the Greeks, or the approaches of Mount Hecla."

Even if smoke consisted of only carbon dioxide and unburnt carbon it would be serious enough. Unburnt carbon may not be a chemical irritant, but by shutting out the light it lowers at once the health, the morality, and the spirits of inhabitants of smoky towns, and by soiling with soot all it touches it prevents cleanliness, which is next to godliness. What love of beauty, what joy in life can be expected in those whose vision is bound, whose homes are sullied, whose flowers are slain by clouds of dirty smoke! Surely grime is the natural soil of crime! How can the poor even be expected to keep open windows if soot enters in place of pure air and sunshine!

Verily smoke were an evil thing if it contained nothing besides carbon dioxide and unburnt carbon; but the unburnt carbon never goes alone, it always indicates other half-burnt products such as the poisonous gases, carbon monoxide, and methane, and it is always associated, as the analyses of soot we have quoted will show, with sulphurous and sulphuric acid.

Coal contains sulphur—about 8 lbs. in every thousand—and the process of combustion converts it into sulphurous acid, which becomes sulphuric acid.

The amount of sulphuric acid produced by the burning of coal is amazing. George E. Davis, late Government Inspector of Chemical Works, makes the following striking calculations: "Coal smoke alone, then, produces about *three million tons* per annum of oil of vitriol (sulphuric acid), most of which no doubt is showered down upon us in the rain : no wonder our gardens do not bring forth their fruits in due season. *Three million tons of oil of vitriol per annum!* This has certainly been going on for twenty years in this proportion, so that during this period we may estimate that over *sixty million tons of oil of vitriol* have fallen over the surface of the British Isles. *Sixty million tons!* Now let us form some idea of this quantity. There are many users of oil of vitriol in Manchester, and nearly the whole of it is made in the Bradford district. From the works there to the user's factory a horse and man will be able to make three journeys a day with eighteen carboys each journey. From these data we shall find that to move this quantity of acid to a distance of 2 miles would require 3,700 horses and men working every day for a year. To put it in another way—suppose a canal was cut in the soil of a uniform width of 20 feet, what would its length have to be to hold the twenty years' production of sulphuric acid resulting from the use of coal as a fuel? To our astonishment we find that if the said canal was 5 feet deep, its length would have to be more than 2,200 miles." Dr. Carpenter, in turn, calculates that "in Widnes, in 1887, 960,000 tons of coal were consumed, giving at the same estimate 120 tons of oil of vitriol a day to be deposited in the surrounding districts."

These figures are perhaps excessive: they do not take into account sufficiently the action of gaseous diffusion and of wind; but even if we discount the figures considerably, it is evident that the amount of sulphuric acid in the air is enormous. The presence of this acid and of carbonic acid in the air necessarily exercises a very corrosive influence and is detrimental both to animal and vegetable life.

Besides carbonic acid, carbon, sulphurous and sulphuric acids, ordinary coal smoke also contains hydro-carbons, ammonia, and iron, and other minerals. An interesting comparative estimate of air pollution can be made by analyses of rain, as the following analyses quoted from Angus Smith will show:—

RAIN TABLE II.—SUMMARY OF RESULTS.

Comparative. Sulphuric Acid (*Sulphates*).

That of Valentia (Ireland) taken as 100.

Scotland—Inland country places	75·5
Ireland—Valentia	100·0
Scotland—Sea-coast country places west	132·2
England—Inland country places	202·2
Scotland—Sea-coast country places average of East and West	206·4
England „ „ west	215·4
Scotland „ „ east	280.6
Waterloo, Liverpool	418·7
German specimens	600·7
Scotland—Towns (Glasgow not included)	604·4
London, 1869	750·5
Birkenhead, near Liverpool	848·2
Runcorn	865·2
Darmstadt—Germany	1068·5
St. Helen's	1215·8
England—Towns	1255·3
Liverpool	1450·2
Manchester 1869	1526·0
Newcastle-on-Tyne	1627·7
Manchester average of 1869 and 1870	1641·9
Glasgow	2571·0
Near an Alkali works (isolated)	2685·0

"Sulphuric Acid," writes Angus Smith, "or sulphate, is a measure of manufacturing activity and also of decomposition.

It is a part of the oxidised, and therefore purified, sewage of the air."

RAIN TABLE XV.—SUMMARY OF RESULTS.

Averages. Albuminoid Ammonia.

	Albuminoid Ammonia Parts per Million.
Ireland—Valentia	0·34
Scotland—Inland country places	0·39
„ Sea-coast „ „ west	1·05
„ „ „ „ average	1·05
England—Inland	1·09
German specimens	1·22
Liverpool	1·59
Runcorn	1·90
London	2·05
Scotland—Towns (Glasgow not included)	2·12
England	2·14
Manchester, 1869	2·17
St. Helen's	2·30
Manchester, 1869 and 1870, average	2·51
„ 1870	2·85
Glasgow	3·00
England—Sea-coast, country place, west	4·00

"Albuminoid ammonia," writes Angus Smith, "is a measure of sewage of air not purified, and includes the most dangerous substances, germs of living things, animal and vegetable."

A similar very interesting analysis of London and Kent snow was made by the *Lancet* in 1906, with the following results:—

	Grains per gallon.	
	London.	Kent.
Free ammonia	0·067	0·030
Organic ammonia	0·039	Nil
Nitrates and nitrites	Nil	Nil
Chlorine	0·840	.0620
Common salt	1·400	1·030
Sulphuric acid	1·730	Nil
Total solid matters	5·60	1·68
Tarry compounds	1·40	Traces

"The evaporated residue" [of the London snow], says the report, "had a marked tarry smell, and brownish fumes smelling exactly like coal tar were evolved on heating. The origin, of course, of empyreumatic substances is coal smoke, and the presence of so much ammonia and sulphur as is indicated in the analysis is to be ascribed to the same source. Hundreds of tons of these impurities, tar, ammonia, and sulphur, must therefore have been brought to earth by this recent snowstorm." The water obtained from the Kent snow, on the other hand, was nearly identical with distilled water. "There was absolutely no sulphur or organic ammonia, and the evaporated residue failed on heating to give off the slightest smell indicating coal tar compounds."

These tables not only give interesting indications of the pollution of the atmosphere, but they also show how rain and snow must purify the atmosphere.

This brings us naturally to the consideration of fog.

Fogs.—Fogs are caused by the condensation of water vapour on particles of dust. If the dust particles are few, the fog is coarse, since each dust particle gets a comparatively large share of moisture. If the dust particles are unequal in size, or with different capacities for condensation, the fog will also tend to be coarse even if the particles be more numerous, since the larger particles with the lower surface tension, and the particles with the greater capacity for condensation, will rob the others. On the other hand, if the dust particles be numerous and with equal surface tension and equal capacity for condensation, the fog will tend to be fine and to persist, and the persistency will be specially marked if the particles have a chemical affinity for water.

The capacity for condensation of dust particles depends on various circumstances, mainly on their power of radiating heat and on their chemical affinity for water. Thus particles of carbon-dust which cool readily, will readily condense moisture (even as a blade of grass condenses dew) and particles of salt-dust with an affinity for water will quickly condense it even before the air is saturated, and will firmly retain it. It is rather strange to think that the salt of the ocean is instrumental in returning to it the water it has given to the air. The salt and water join again and return to the ocean.

Aitken has shown further that if certain vapours, especially ammonia and sulphuric acid, are present in the air they occasion or aggravate fog. "The fog," he says, "produced when steam has been blown into air in which a very little sulphur has been burned is so dense that if ever fog was 'cut with a knife' it might or should be. So dense is it that it is impossible to see through a depth of more than 5 centimetres of it." The addition of ammonia increases the fog. "If we make artificial fogs with sulphur fumes and ammonia the fog is so heavy it can be poured from one vessel to another." In this case sulphate and sulphite of ammonia are probably the active agents.

City Fogs.—In cities there are all the elements present to form a fine persistent fog. There are carbon particles, salt particles, ammonia and sulphuric acid; and plenty of them. In the air which precedes and accompanies fogs dust particles numbering 45,000 to 80,000 per cubic centimetre have been counted. It is often assumed that city fogs come from the sea; but as a rule they are what are known as "radiation" fogs: they are formed *in situ* by a condensation of moisture on the dust in the air. A considerable number of London fogs are produced, according to the Hon. Rollo Russell, by the meeting of cold north-east and warm south-west winds. Once formed, a fog readily thickens and darkens, owing to the carbon particles and vapours caught in it, and forms a chemical pall between the city and the sky. The moisture condensing on the carbon particles dissolves out of them the gases they occlude, and also weighs them down, and they sink earthward as a wet, acrid cloud.

If the dust particles be very numerous they may condense so little moisture as to seem dry, and as to evaporate to actual dryness when they touch the warmer ground. Such a fog is known as a dry fog, and owing to the concentrated nature of its chemical solutions may be very irritating.

In some cases fogs hang a few hundred feet above the ground.

The hydrocarbons of smoke forming an oily film on the surface of the individual fog droplets tend to prevent them from evaporating.

The more carbon a fog contains the blacker it is. The general result of a fog is to shut out sunlight and fresh air, and to half suffocate unfortunate citizens in a cloud of noxious chemicals. It contains all the irritating vapours of smoke in a concentrated form and it also prevents the escape of the city-made carbon dioxide—the carbon dioxide of respiration as well as of combustion. Even without smoke there would be fogs, but it is chiefly the concomitants of smoke that make a city fog so pernicious and persistent. Smoke in a dry atmosphere may quickly diffuse away and do little harm, and a moist fog in a smokeless atmosphere may do little harm, but the combination of smoke and water is an undoubted curse.

According to the nature of the chemicals in the fog so do its colour and acridity vary: it may be brown, or black, or green, or yellow, and it may be most irritating or almost bland. When a city is large and burns a large quantity of coal, however, the fog is certain to be usually dark-coloured and offensive. When we realise that in London more than a million chimneys "breathe forth simultaneously smoke, soot, sulphurous acid, vapour of water and carbonic acid gas and the whole town fumes like a vast crater," when we consider that about 10,000,000 tons of coal including thousands of tons of sulphur are burnt yearly, we can hardly expect the fog to be very desirable gravy. Before the Noxious Vapours Commission of 1876 the following evidence was given:—

"James Maclean, Esq. (of Messrs. Tennant & Co., Glasgow) says: 'We burn at St. Rollox 127,000 tons of coal, giving 1 per cent. of sulphur, equal to 1,270 tons of sulphur given off in the form of sulphuric acid. In Glasgow, assuming 1½ tons of coal to each person, we get 10,000 tons of sulphur; and assuming that the manufacturers use ten times as much coal as used for domestic purposes we get 100,000 tons of sulphur.'"

"James Brook, Esq. (Managing Director of the British Alkali Works at Widnes) gave table of sulphurous acid produced at works of witness during twelve months: Sulphur sent up chimney and otherwise lost in manufacturing process equals 212 tons. Sulphur in fuel during same period, 50,000 tons at 1½ per cent. equals 750 tons, equals sulphurous acid 1,500 tons."

If smoke be bad, fog is ten times worse: it contains all the carbon dioxide, hydrocarbons and acrid vapours of smoke in a concentrated form and the falling soot is like a sponge soaked in acid.

The increase in the carbon dioxide and sulphurous acid of the air during London fog is well shown in the table on the following page:—

Even regarded in its financial aspect, fog is a very serious matter. The Governor of the Gas Light and Coke Company wrote to the *Times* on January 24, 1885: "Ninety-six million cubic feet of gas were sent out during the 24 hours ending at midnight on Tuesday. This quantity was an increase on that of the corresponding day in 1884, which may be taken

CARBONIC ACID IN LONDON AIR.

Date.		Carbon Dioxide, Per Cent.
January 19, 1882	Slight white fog	·048
January 25, 1882	Dense black fog	·105
February 1, 1882	Very fine	·047
February 3, 1882	Slight fog	·062
February 4, 1882	Dense black fog	·107
December 8, 1882	Fine	·040
December 10, 1882	Thick white fog	·094
December 11, 1882	Thick white, darker	·110
December 11, 1882	Later very dark	·141
March 31, 1883	Fine	·037
April 3, 1883	Very foggy	·133

In some cases the carbonic acid percentage has been known to rise as high as ·350 during fogs.

SULPHUROUS ACID IN MANCHESTER AIR (DETERMINED BY MANCHESTER AIR ANALYSIS COMMITTEE).

(*Milligrams of Sulphur Trioxide per* 100 *Cubic Feet.*)

	Minimum.	Maximum.	Average.
September	0·7	3·5	1–2
October	0·7	6·0	2–4
November	2·0	12·0	6–8
December	3·0	30·0	6–10

(*Milligrams of Sulphur Trioxide in* 100 *Cubic Feet.*)

Date.	Outskirts.	Centre of Town.
September 5	0·7	1·8
October 14	0·8	3·53
November 5	1·7	4·9
November 10	2·5	4·1
November 13	3·3	7·6
November 17	2·0	5·9
November 19	2·96	8·4
November 22	4·2	Fog 9·7
November 27	9·3	Fog 15·7
December 17	2·3	9·2
December 21	16·5	Fog 32·2
December 22	12·7	Fog 22·6
December 23	12·7	Fog 25·8

to have been an ordinary January day, of 35 per cent., or over 35,000,000 feet. The price being 3s. per cubic foot, the public had to pay this one company £5,250 extra on account of the fog. Nine thousand five hundred tons of coal were carbonised to produce the 96,000,000 feet—the largest quantity we have ever sent out in one day."

The Hon. Rollo Russell calculates the annual loss to the people of London from fog as follows :—

	£
Extra washing (including extra soap used for all purposes). Dr. Arnott's estimate some years ago was much higher, namely, £2,500,000	1,100,000
Dresses, curtains, carpets, and all textile fabrics damaged and renewed	200,000
Wall-papers replaced, time and labour	50,000
Houses painted inside or outside, say once in 5 years instead of once in 25 years, and whitewashing ceilings, &c.	100,000
Restoring gilding, metal work, shop fronts, names of streets, advertisements, stations, pictures, works of art, monuments, theatres, &c.	100,000
Slow destruction of stonework, granite, marble, &c., on public and private buildings	1,000
Extra chimney-sweeping	20,000
Window-cleaning of public and private buildings, including station roofs, &c., time of servants included	50,000
Extra gas, candles, and lamps used	40,000
Escape of $\frac{1}{100}$th part of fuel into atmosphere ...	100,000
Depreciation of house property, loss of time by illness caused by fogs, loss of time and money by travelling of persons who would otherwise live in London... ... ... Not estimated	
	£1,761,000

The Effect of Smoke and Fog on the Health.—The pernicious effect of the chemicals of smoke on the health has been probably overestimated. Ordinary smoke containing carbon, carbon dioxide, carbon monoxide, and sulphur gas in ordinary proportions, acts on the health chiefly in an indirect fashion. It diminishes the sunlight and it is a source of dirt. Thus it depresses the spirits of the inhabitants of the smoky towns, and leads to squalor, discomfort, and consequent intemperance and degradation. Even in this respect we must not blame smoke too much ; we must remember that there are many circumstances besides smoke which tend to demoralise the poor in large cities. It may be pointed out that many peasants have no proper chimneys in their dwellings, and live indoors in a very smoky, sooty atmosphere, and that engine-drivers and the officials on underground railways must breathe very smoky air, and that none of these classes seem to suffer in their health from the air they breathe. It is only when the smoke becomes mixed with moisture and concentrated that animal and plant life suffer, and the blacker the smoke the more pernicious will the mixture be. It will be the more pernicious because it will interfere more with sunlight, and because the black smoke is at once a measure of the amount of half-burnt matter, and a means of their retention, and a nucleus for condensation of vapour. Black, damp, concentrated smoke is undoubtedly harmful to man and plants, both through the sunlight it debars and the noxious vapours it helps to retain.

When this smoke is further concentrated, as is often the case in all large cities, into a fog, its evil effects are exaggerated. Always during city fogs sickness increases and the death-rate rises. The Hon. Rollo Russell writes : " After a fortnight of dense fog the deaths in London for one week, ending January 2, 1892, exceeded by 1,484 the average number, being at the rate of 42 per thousand. Increases took place in the following diseases : Measles, 114 per cent. ; whooping-cough, 173 ; phthisis, 42 ; old age, 36 ; apoplexy, 58 ; diseases of the circulatory system, 106 ; bronchitis, 170 ; pneumonia, 111 ; other respiratory diseases, 135 ; accidents, 103."

A fog in 1880 was even more fatal, as the following figures he gives will show :—

Week Ending—	Weather.	Deaths.		Below or Above Average.
Jan. 10 ...	—	Total	1,754	− 76
		From respiratory diseases	455	− 40
Jan. 17 ...	—	Total	1,730	− 30
		Respiratory	512	− 42
Jan. 24 ...	Great cold ...	Total	1,900	+ 139
		Respiratory	559	+ 104
Jan. 31 ...	Great cold and fog	Total	2,200	+ 607
		Respiratory	757	+ 341
Feb. 7 ...	Great cold and extremely dense fog	Total	3,376	+1,657
		Respiratory	1,557	+1,118

The results, he says, "are in the main attributable to the concentration of the ordinary constituents of London air, with moisture and intense cold to help their deadly work. The majority of the fatal cases were in weakened constitutions, though many were among the robust."

Similar evidence is produced by J. B. Cohen in the table quoted on the following page.

So thick are fogs sometimes that animals are actually suffocated. In London during a dense fog several cattle were suffocated at a Christmas show, and the suffocation of thousands of people by a fog is quite within the limits of possibility.

These are the evident results of fog on the health: but no doubt much chronic ill-health—anæmia, neurasthenia, dyspepsia, &c.—may be produced by such polluted air, and it is very probable too that deficient light will stunt men as well as vegetation. The inhabitants of the Itura Forest in Central Africa are Pygmies, and the inhabitants of smoky cities are often much below average height.

Much of the bad effect of fog is, of course, due not to

SICKNESS AND MORTALITY IN MANCHESTER DURING THE MONTHS OF DECEMBER (1890), JANUARY, AND FEBRUARY (1891).

(*Estimated Population*, 1891.)

Week Ending—	Weather (Town Hall).	Thermometer.		Sickness (Weekly Numbers).		Deaths (Weekly Numbers).	
		Maximum.	Minimum.	General Treated at Public Expense.	Infectious Reported to Medical Officer.	All Causes.	Respiratory Diseases and Phthisis.
December 6 ...	Dry and cold, thawing... ...	48·6	29·8	780	70	244	85
December 13 ...	Dry east winds, hard frost, some fog	40·1	25·8	719	83	238	87
December 20 ...	Dry east winds, hard frost, some fog	40·1	18·6	672	70	294	121
December 27 ...	Dry east winds, hard frost (dense fog three days)	40·8	15·8	448	56	393	204
January 3 ...	Overcast, severe frost	41·8	26·0	691	59	328	165
January 10 ...	Overcast (foggy two days) ...	40·8	21·7	801	52	341	153
January 17 ...	Overcast (foggy two days) ...	43·8	27·8	853	66	336	156
January 24 ...	Overcast	48·7	17·0	708	51	278	109
January 31 ...	Overcast (clear two days) ...	51·6	36·0	818	61	263	95
February 7 ...	Overcast (clear two days) ...	51·4	34·7	802	52	211	78
February 14 ...	Overcast	50·1	37·2	866	62	232	91
February 21 ...	Dull (dense fog two days) ...	52·7	27·6	787	54	291	104
February 28 ...	Clear (dense fog one day) ...	56·7	29·0	929	62	257	113

the chemicals it contains, but solely to the depressing effect of damp and cold.

We have talked so far of the effect of ordinary smoke, and ordinary smoke-fog. When we come to the effect of smoke polluted with other chemical vapours, such as hydrochloric acid and sulphuretted hydrogen and arsenical vapours, the matter becomes much more serious, especially since the latter most poisonous gas is given off not only from chimneys but from waste heaps. Evidence of the destructive nature of hydrochloric acid was given before a Royal Commission by Stone, a market gardener. He described how all the fir-trees and most of the other trees in a once famous park were destroyed by hydrochloric acid fumes. In the neighbourhood of chemical works generating this gas all vegetation is destroyed. There can be no doubt that the gas irritates the respiratory passages and causes pulmonary disease.

Sulphuretted hydrogen, which used to be largely generated in sulphate of ammonia and tar works, and from alkali waste, is a very poisonous gas. Happily the gas is now usually utilised to make manure and sulphuric acid; but in former days it was a fruitful source of ill-health and mortality.

Arsenical vapours are given off chiefly from lead and copper works, and horses and cattle are sometimes killed by the fumes. The subject of poisonous chemical fumes, however, is a very large one, and we have not space here to discuss the subject fully.

Measures against Smoke and Fog.—The unpleasantness and undesirability of smoke have been a subject of legislation and protest for hundreds of years. In the reigns of Edward I. and Elizabeth proclamations were issued forbidding the use of stone-coal in London during the sitting of Parliament, in order that the health of the Knights of the Shire might not be hurt.

In the reign of Edward II. coal smoke was forbidden. In 1648 the citizens of London petitioned Parliament against the use of stone-coal from Newcastle.

In 1661 the well-known writer Evelyn, in a book called "Fumifugium," addressed to King Charles, complains: "This is that pernicious smoke which sullies all her glories, superinducing a sooty crust or furr upon all that it lights, spoiling the movables, tarnishing the plate, gildings and furniture, and corroding the very iron bars and hardest stones with these piercing and acrimonious spirits which accompany its sulphur, and executing more in one year than exposure to the pure air of the country could effect in some hundreds.

"It is this horrid smoke which obscures our churches and makes our palaces look old, which fouls our clothes, and corrupts the waters, so as the very rain and refreshing dews which fall in the several seasons, precipitate this impure vapour, which with its black and tenacious quality spots and contaminates whatsoever is exposed to it."

"It is this which scatters and strews about those black and smutty atoms upon all things where it comes, insinuating itself into our very secret cabinets, and most precious repositories. Finally it is this which diffuses and spreads a yellowness upon our choicest pictures and hangings which does this mischief at home, is Avernus to fowl, and kills our bees and flowers abroad suffering nothing in our gardens to bud, display themselves or ripen.

"The consequence then," he proceeds, "of all this is, that (as was said) almost one half of them who perish in London die of phthisical and pulmonic distempers; that the inhabitants are never free from coughs and importunate rheumatisms, spitting of importunated and corrupt matter for remedy whereof there is none so infallible, as that in time the patient change his air and remove into the country. Such as repair to Paris (where it is excellent) and other like places perfectly recovering of their health, which is a demonstration sufficient to confirm what we have asserted concerning the perniciousness of that about this city produced only from this exitial and intolerable accident."

Evelyn's protest is so interesting that we need not apologise for this lengthy quotation.

Last century when industries increased the nuisance became intolerable, and as a result of Select Committees in 1819, 1843, 1845, and of Reports from the General Board of Health, very useful legislative measures, local and central, have been taken to abate the nuisance.

The Public Health Act of 1891 enacts (Section 91 Clause 7): "For the purposes of this Act, any fireplace or furnace which does not, so far as practicable, consume the smoke arising from the combustible used therein, and which is used for working engines by steam or in any mill, factory, dyehouse, brewery, bakehouse, or gaswork, or in any manufacturing or trade process whatever, and any chimney (not being the chimney of a private dwelling-house) which emits black smoke in such quantities as to be a nuisance, shall be deemed a nuisance and liable to be dealt with summarily in the manner provided by this Act."

The London County Council permits black smoke for five minutes after the lighting of a furnace. Other towns allow as much as fifteen minutes.

In Sheffield the limits are as follows:—

1 boiler	2 minutes black smoke in the hour
2 boilers	3 „ „ „ „ „
3 „	4 „ „ „ „ „
4 „ and more...	6 „ „ „ „ „

The law has made a distinction between black smoke and white smoke, and, as we have seen, it is a distinction with a difference.

Legislation has also turned its attention to the question of particular chemical impurities such as hydrochloric acid. The Alkali Works Regulation Act of 1863 enacted that smoke must not contain more than 5 per cent. hydrochloric acid. In 1874 the Act was amended to enact that the amount of hydrochloric acid discharged must not exceed $\frac{2}{10}$ of a grain in a cubic foot of escaping air in chimney or flue, and the Act of 1881 enacted further that the best method known must be employed.

Law, therefore, has done something to prevent the pollution of the atmosphere, and a good deal more has been done by the invention of various methods of producing a smokeless fire. The inventions are legion—Meldrum's Koker Stoker, Cass's Coking Stoker, Vicars Mechanical Stoker, Murphy's Furnace, Wilson Smokeless Process, Wegener's System, Gregory and Foster's Smoke Consumer, Whelper and Storer's System, the Arnott Grate, the Marsh Grate, and many others.

Mr. Brodie, the clerk of the weather who is responsible for the daily forecasts issued by the Meteorological Office, gave some remarkable figures at a meeting of the Smoke Abatement Society in illustration of the progress made in combating the smoke nuisance:—

WINTER MONTHS.

Five-year Periods.	Average Annual Days of Black Fog.	Average Annual Hours of Sunshine.
1883–1888	25	50
1888–1893	23	63
1893–1898	22	69
1898–1903	17	74
1903–1908	10	95

The winter of 1908 includes the first two months of the year 1909. These figures, Mr. Brodie said, meant that

London is now a cleaner and healthier town than twenty-five years ago. The daily sunshine average during the three winter months has increased from 33 minutes to 1 hour 3 minutes. This remarkable improvement is chiefly due to improved methods of fuel combustion.

Together Law and Invention have certainly improved matters, but, as every London fog demonstrates, there is still room for improvement.

A very hopeful solution of the smoke problem was suggested many years ago by a Mr. Peter Spence. Mr. Spence made the suggestion that all the smoke of a city should be conducted by the sewers to a few enormous chimneys, where it could be completely burnt. He pointed out that the sulphuric acid in the smoke would have a disinfectant effect on the sewage, and that thus the plan would have indirect advantages. This was the plan Sir B. W. Richardson proposed to adopt in his model city Hygeia.

Such a scheme, however, would cost a great deal, and would be applicable only if the system began when the city began, and grew with the city.

Still something must be done. In the words of Alfred Russell Wallace: "The huge and ever-increasing cities, the vast manufacturing towns belching forth smoke and poisonous gases, with the crowded dwellings where millions are forced to live under the most terrible insanitary conditions, are witness to a criminal apathy, an incredible recklessness and inhumanity. Yet this is the one great and primary essential of a people's health and well-being, to which everything should for the time be subordinate. This is the gospel which should be preached in season and out of season till the nation listens and is convinced. Let this be our claim: pure air and pure water for every inhabitant of the British Isles. Remember, we claim to be a people of high civilisation, of advanced science of great humanity, and of enormous wealth."

The Air of Mines.—The air of mines contains less oxygen and more carbon dioxide than ordinary air—about 20 per cent. oxygen and ·2 per cent. carbon dioxide—and it is often polluted with dangerous gases—carbon monoxide, methane, and sulphuretted hydrogen.

Carbon monoxide is a colourless, odourless gas which is always produced when carbonaceous matter is burnt with an insufficient supply of air, and it is one of the poisonous gases of the after-damp of mines.

It is a very dangerous gas, since it enters into combination with the hæmoglobin of the blood and renders the haæmoglobin unable to take up the oxygen necessary for life. The compound of carbon monoxide and hæmoglobin gives the blood a striking bright red colour. Sir Clement Le Neve Foster, who was poisoned by carbon monoxide, gives a very interesting account of his experience. "A curious fact," he writes, in his report to the Home Secretary, "is that we all sat without moving or trying to escape. The foot of the ladder was close by, yet none of us made any effort to go to it and ascend even a single rung. We none of us tried to walk a dozen steps, which would have led us to the other side of the shaft partition, where we all knew that there was a current of better air. We simply sat on and on; Mr. Williams remained motionless, like a statue; Captain Reddicliffe, on the other hand, was shouting and groaning nearly all the time, while Clague was moving his arms. Of all this I was perfectly conscious, though rooted to my seat. By my side was one of the pipes conveying compressed air, in which a hole had been punched some days before. I was perfectly conscious that fresh air was a good thing for me, and I frequently leant over and put my mouth to the hole and inhaled a good breath. How soon I realised that we were in what is commonly called 'a tight place' I cannot say; but eventually, from long force of habit, I presume, I took out my note-book. At what o'clock

I first began to write I do not know, for the few words written on the first page have no hour put to them. They were simply a few words of goodbye to my family badly scribbled. The page is headed '2 p.m.,' and I perfectly well recollect taking out my watch from time to time. . . . My notes at 2 p.m. were as follows: '2 p.m. Goodbye, we are all dying, your Clement, I fear we are dying, goodbye, all my darlings all, no help coming, goodbye we are dying, goodbye, goodbye we are dying, no help comes, goodbye goodbye.' Then later, scribbled over some 'goodbyes,' I find: 'We saw body at 130, and then all became affected by the bad air, we have got to 115 and can go no further, the box does not come in spite of our ringing for help. It does not come, does not come. I wish the box would come. Captain R. is shouting, my legs are bad, I feel very—my knees are . . .' There is writing over other writing, as if I did not see exactly where I placed my pencil, and then: 'I feel as if I were dreaming no real pain, goodbye, goodbye, I feel as if I were sleeping. 2.15 we are all done goodbye my darlings.' . . . Judging by my notes, I did not realise thoroughly that we should be rescued. Among them occur the words: 'No pain it is merely like a dream, no pain; no pain, for the benefit of others I say no pain at all, no pain no pain.' . . . The general sensation was like a bad dream, and yet I was able to reason properly and write intelligibly, though in a disjointed fashion."

Dr. J. S. Haldane, who examined two samples of the air, found in one 1·07 per cent. of carbon monoxide and in the other 1·10 per cent., and stated in his report that the air, even when diluted with nine times its volume of fresh air, would still be capable of rendering a man incapable of walking.

Methane.—Not carbon monoxide, however, but methane, or marsh gas, is the great danger of mines. It is formed when organic substances, especially vegetable substances, are decomposed in the absence of air and in the presence of water. Hence it is found in marshes, and in the seams of coal-mines. It is a colourless, odourless gas, which burns with a clear blue flame. When mixed with about 10 volumes of air it forms a very explosive mixture, and most of the great colliery disasters have been caused by explosions of this nature. It is not, however, a poisonous gas like carbon monoxide, and can be breathed without harm if a sufficient quantity of oxygen be present for respiratory purposes.

Hydrogen is sometimes found in mines. It also is explosive when mixed with air and oxygen. Sulphuretted hydrogen—a gas with the odour of rotten eggs—also occurs in small quantities. Sulphuretted hydrogen is a poisonous gas, and if breathed in large quantities quickly causes death.

Gunpowder blasting adds to the air of mines carbon dioxide, carbon monoxide, hydrogen, hydrogen sulphide, and dust consisting of potassium sulphate, carbonate, hyposulphite, sulphide, sulpho-cyanide and nitrate, with carbon, sulphur, and ammonium sesquicarbonate.

Ground Air.—Ground air—air, that is to say, mixed in the soil—is always richer in carbon dioxide and poorer in oxygen than ordinary atmospheric air. The exact proportions vary with the season, with the rainfall, with the depth, with the organic matter in the ground, with the atmospheric pressure and temperature, &c.

The following table is given by Fleck :—

GROUND AIR FROM DEPTHS OF SIX, FOUR, AND TWO METRES.

	6 Metres.		4 Metres.		2 Metres.	
	Minimum CO_2.	Maximum CO_2.	Minimum CO_2.	Maximum CO_2.	Minimum CO_2.	Maximum CO_2.
Oxygen... ...	14·94	14·85	15·67	16·79	16·33	19·39
Carbonic Anhydride ...	4·22	7·96	4·11	5·56	2·99	2·91
	19·16	22·81	19·78	22·35	19·32	22·30

A fall in the barometer or a rise in temperature, by liberating ground air, tends to increase the proportion of carbon dioxide in the air above the ground.

Ground air may, of course, be polluted with sewage gases, such as sulphuretted hydrogen, ammonium sulphide, carbon bisulphide, marsh gas, &c., and may be drawn into dwelling-houses through many feet of soil.

Sewer Air.—Sewer air varies greatly in its composition. It usually contains an excess of carbon dioxide and the gases which have just been mentioned. If it leak into a house in any considerable quantity it may cause impaired health among the inmates—anæmia, diarrhœa, headache, "sewer-air throat," fever, &c.—but its effects will depend on the state of the sewage. The air of the main sewers is comparatively pure, and the workmen employed in them enjoy good health.

Marsh Air.—The air of marshes contains excess of carbon dioxide, and often marsh gas, hydrogen, sulphuretted hydrogen, and ammonia.

Offensive Gases from Trades.—According to Notter and Firth ("Theory and Practice of Hygiene"), the gaseous waste products of the chief industries are as follows:—

"Hydrochloric acid gas, from alkali works.
Sulphur dioxide and sulphuric acid, from copper works—bleaching.
Hydrogen sulphide, from several chemical works, especially those producing ammonia.
Carbon dioxide, carbon monoxide, and hydrogen sulphide, from brick-fields and cement works.
Carbon monoxide, from iron furnaces, may amount to from 22 to 25 per cent.; from copper furnaces, 15 to 19 per cent.
Organic vapours, from glue refiners, bone-burners, slaughter-houses, knackeries.
Zinc fumes, from copper smelting.
Phosphoric fumes, from manufacture of matches.
Carbon disulphide, from some india-rubber works.

"The majority of the gaseous products from industries are both irrespirable and offensive, the more markedly hurtful being the vapours of chlorine, iodine, bromine, arsenic, and phosphorus, with carbon monoxide, sulphuretted hydrogen, and the compounds of carbon and sulphuric acid. It is true that, unless favoured by the particular conditions of wind and weather, in most instances the presence of these gases is not noticed by any one outside the factories in which they are produced; still the majority are so irritating as to constitute, if in any appreciable quantity, very serious atmospheric impurities."

CHAPTER XI

DUST AND GERMS

ACCORDING to the Hebraic cosmogony man was made from the dust, and in man's life dust still plays a very important part. The atmosphere is full of dust: it is dust, as we have seen, that makes the sky blue and diffuses the sunlight, and, paradoxical though it may seem, it is dust that also brings the rain and hides the noonday stars; and dust has many other equally obscure and important functions.

Source of the Dust in the Atmosphere.—The dust in the air is obtained from numerous sources and is manifold in character. Most of it is torn by wind, or belched by volcanoes from the earth's crust, and a considerable amount of it consists of minute grains of salt derived from the sea-spray. Every one who has been in South Africa knows how vast a dust-storm may be, and to what distance clouds of dust may be carried. The writer has seen in the Canary Islands clouds of dust sufficient to obscure the sun, though the dust had come all the way from the African mainland; and red dust from China has been found in the air of California. Ehrenberg detected organisms belonging to Africa in the air of Berlin, and fragments of Infusoria belonging to the steppes of America in the air of Portugal; while the smoke of the burning of Chicago reached even to the Pacific coast. How widely scattered volcanic dust may be is testified by the wonderful sunsets which so often follow great volcanic eruptions. The dust of Krakatoa, consisting chiefly of glassy pumice, was found for years in our atmosphere, and probably travelled several times round the world, bringing rain and glorifying sunsets. After an eruption in Iceland there was a dust fog over Western and Central Europe for some weeks. The presence of sea-salt in the air is easily detected even a considerable distance from the sea. Thus the great deserts of the world —the Sahara, the Kalahari, the Karroo, the great Australian deserts, the great plains of Central Asia, the great volcanoes of the world—Vesuvius, Cotopaxi, Etna—all help to keep the sky blue and the grass green, all help to modify solar radiation and rainfall for the welfare of man. *En passant*, too, it may be mentioned that the rain of dust on the sea is a boon to the fishes, for every grain of dust as it sinks in the water carries with it a small quantity of air.

Among the important sources of dust, too, we must count the smoke of human habitations and factories.

But dust is obtained not only from terrestrial but also from interplanetary sources: the air is laden not only with the dust of the world, but also with the dust of meteorites. It has been calculated by Professor Newton that about 20,000,000 meteorites, each large enough to be seen as a shooting star, reach our atmosphere every twenty-four hours, and these furnish a large amount of dust which can be recognised not only in the air but in the silt at the bottom of the sea.

Dust from the soil, from the sea, from interplanetary space may be considered dust proper, and consists chiefly of silica, aluminium silicate, calcium carbonate, calcium phosphate, magnesia, iron oxide; but in addition to such dust air may contain other solid particles which must be classed as dust, *e.g.*, unburnt carbon, spores of fungi, pollen grains, fluff of various kind, bits of insects, starch, particles of iron, steel, coal, stone, microbes, &c.

One of the most important functions of the dust is to limit the humidity of the air, by causing precipitation of moisture in the form of rain, and to help to control temperature by the formation of clouds, mists, and fogs. When water vapour in the atmosphere condenses, it almost always condenses on a solid surface, and the dust particles offer such a surface. Except for dust there would be neither clouds nor fogs, and if it *did* rain the rain would come from a cloudless sky. In the absence of dust, as soon as the air became supersaturated the water vapour would use everything on the surface of the earth as a condenser, and in the words of John Aitken, who has made a special study of the subject: "Every blade of grass and every branch of tree would drip with moisture deposited by the passing air; our dresses would become wet and dripping, and umbrellas useless; but our miseries would not end here. The insides of our houses would become wet; the walls and every object in the room would run with moisture."

The type of condensation produced by dust will depend chiefly on the amount of dust present. If there be a large amount of dust, then each dust nucleus will obtain only a small amount of water, and thus a fine fog will be produced; while if the dust be not so plentiful each dust nucleus will obtain a larger share of the water and thus a coarse fog will be produced. Certain kinds of dust, *e.g.*, sodium chloride, by reason of their chemical affinity for water, are specially good condensers. We will deal with this subject of condensation more fully when we deal with the question of town fogs.

Dust, though almost universally present in the known atmosphere, is very irregularly distributed.

Aitken, who counted the dust particles in air in various localities, found great variations in their distribution, both as regards place and time. Thus on the top of a hill at Hyères he found 3,550 to 25,000 particles per cubic centimetre according to the direction of the wind, and on the top of a hill near Cannes he found 1,550 to 150,000 per cubic centimetre according to the direction of the wind, the greater number in both cases occurring when the wind blew from populated localities. At Mentone, Ballagio, Baveno, and in a special experiment at Falkirk the same relationship between dust particles and the direction of the wind was noted. On the top of the Rigi the number of particles varied between 210 to a little over 2,000 per cubic centimetre. On the Eiffel Tower the number varied between 226 and 104,000 per cubic centimetre. In a garden in Paris 160,000 to 210,000 were found. In London 48,000 to 116,000 were found. In Glasgow 170,000. On the top of Ben Nevis 335 to 473 were counted—on one occasion he found as low as 16, and Mr. Rankin once found none. In a general way Aitken's results show that as a rule the air is most free from dust in the wilds and most laden with dust in large cities. Rain and wind both decrease the number of dust particles.

Similar examinations by other observers had similar results. Professor Melander, of Helsingfors, made 268 examinations of the air at Salève, Biskra, Torhola, Loimola, Kristianssund, and Grip, and found above 500 particles of dust in every specimen except one. Dr. Macfadyen and Mr. Lunt found in the yard of a London house 5,000,000 dust particles.

Mr. E. D. Friedlander found 2,000 to 4,000 c.c. in the air over some parts of the Western Atlantic, 280 to 2,125 per c.c. over the Pacific Ocean, 200 to 500 over the Indian Ocean, 280 to 1,375 over the Arabian Sea, 383 to 490 over the Red Sea, and 875 to 2,500 over the

Mediterranean. On the summit of the Brieshorn (13,600 feet) Friedlander found only 140.

Indoors dust particles are more numerous. In the meeting-room of the Royal Society of Edinburgh 275,000 particles were found before meeting, and after an hour and three-quarters 400,000. Near the ceiling the number was 3,000,000, and after an hour and three-quarters 3,500,000. In another room, Aitken's laboratory, 1,860,000 were found, and near the ceiling 5,420,000. Smoking-rooms contain even more, since a smoker sends 4,000,000,000 particles into the air with every puff he makes.

Dust decreases the transparency of the atmosphere, especially if the atmosphere be also humid. What is known as haze is really dust, carrying a minute amount of moisture.

The mineral dust in the air produced by natural agencies is rarely sufficient *quā* dust, to cause more than temporary irritation of the respiratory mucous membranes; but the alkaline dust of the United States has been considered responsible for the prevalence of nasal catarrh in that country, and a very plausible though unsuccessful attempt was made some years ago by H. Harries (on the suggestion of Professor Ragona and Dr. Darwin) to prove that influenza was caused by volcanic dust, and that there was a connection in time between volcanic eruptions and influenza epidemics. Ordinary atmospheric dust, free from germs, causes wonderfully little irritation of the healthy respiratory mucous membranes. Even the African dust-storms do not seem to have a detrimental effect on the lungs of consumptive patients, and since the dust is aseptic, any irritation they cause may possibly prove beneficial by causing a healing fibrosis. Even the carbon dust in the air which blackens the lungs causes very little damage to the lung tissue. There is nothing very surprising in this comparative invulnerability of the lungs to dust: the air passages are provided with a mucous secretion and with ciliated epithelium, and are guarded by the tonsils and the nostrils in preparation for such attacks.

When, however, we come to the mineral dusts produced by man there is quite another story to tell, but it is told so well by Sir Thomas Oliver in his work, "Diseases of Occupation," that we need here merely adumbrate the subject.

The general effect of artificial mineral dusts of an irritating character breathed for a long period is to cause an inflammatory condition of the lung tissue, resulting in the formation throughout the substance of the lung of a fibrous tissue, which in time completely destroys the lungs. The rapidity of this destructive process varies with the character of the dust, and, according to the nature of the dust, has in some cases received special names. The general name for the invasion of the lung tissue by fibrous tissue produced by dust irritation is *pneumokoniosis*. When the dust is coal dust the condition is known as *anthracosis*, when mineral dust *silicosis*, when iron or steel dust *siderosis*.

Dust not only causes this inflammatory change in the lungs, but it also renders them much more liable to infection by certain microbes, notably the microbes of tuberculosis and pneumonia. Hence we hear of "stonemasons' phthisis," and "steel-grinders' phthisis," and "potters' rot."

A fork-grinder said to Dr. J. G. Hall, of Sheffield: "I shall be 36 next month, and you know that is getting an old man at our trade." A man of 26 said he reckoned that in about two more years at his trade he might begin to think of dropping off his perch, adding, "You know a knife-grinder is an old cock at 30."

Dr. Tatham, in an article on "Dangerous Trades," gives the following statistics, showing the relationship between phthisis and dusty trades:—

Occupation.	Comparative Mortality Figures (all causes).	Mortality Figures.	
		Phthisis.	Diseases of the Respiratory Organs.
Agriculturist	602	106	115
Pottery: Earthenware Manufacturer	1,706	333	668
Cutler	1,516	382	518
File-maker	1,810	402	423
Glass-maker	1,487	295	445
Copper-worker ...	1,381	294	406
Iron and Steel Manufacturer	1,301	195	450
Stone Quarries... ...	1,176	269	307
Brass-worker	1,088	279	273
Chimney-sweep ...	1,311	260	291
Lead-worker	1,783	148	397
Cotton Manufacturer ...	1,141	202	338

Fifty or sixty years ago coal-miners were very subject to consumption: now they are less subject to consumption than the ordinary population. The reason for this usually given is better ventilation of the mines, but there seems to the writer little doubt that the great decrease in consumption among miners is an interesting illustration of the survival of the fittest. The occupation of coal-mining is hereditary, and the heavy death-rate in former generations must have weeded out vulnerable stock. Further, it must be remembered that very few germs can be found down coal-pits.

On the Rand the mortality from pulmonary diseases among miners is very high, and in many cases death seems to be due solely to the irritation of the dust and to be uncomplicated by tubercular infection. The death-rate from pulmonary diseases at the Australian mines is likewise very high, though not so high as on the Rand.

The dust raised in rock-drilling for tin is particularly dangerous, and the mortality from lung diseases among tin-miners is very heavy.

The highest dust death-rate, however, is found among ganister miners. Ganister is a hard, siliceous stone which is ground into dust and then made into bricks, and the death-rate among the ganister-grinders reaches the extraordinary figure of 179·8 per thousand. The disease of which they die is a form of silicosis, and the lungs become converted into hard, almost solid material, composed for the most part of dense fibrous tissue.

Stonemasons' phthisis, due to the dust of stone, begins as a simple pneumokoniosis, but usually acquires tubercular characters in the course of time.

Potters' rot is due to the inhalation of flinty dust produced in the various processes of making pottery. Professor Oliver, in his work, "Diseases of Occupation," states: "The atmosphere in which the brushers-off, the finishers, and the porcelain-makers generally work contained 640 million particles of dust per cubic metre of air, while several of the finishers, *i.e.*, the persons whose work consists in removing the excess of the dried glaze on the ware, are often breathing an atmosphere containing 680 million particles of dust to the cubic metre." It is little wonder that bronchitis and phthisis are common.

Besides mineral dusts with irritative properties, mineral dusts with poisonous chemical properties may also be inhaled or swallowed. In pottery-work, in file-making, in printing, in glass-polishing, and in many other industries, lead-poisoning from lead-dust is not uncommon. Workers with arsenic, copper, brass, zinc, &c., may suffer from poisoning by the dust of these metals. But the whole subject of such poisoning is discussed so fully by Professor Oliver that we need not enter into it here.

Even more dangerous than the mineral dusts we have mentioned is organic dust. In all air there is a certain amount of organic dust. In the air of the British Museum, where I write these words, about half the dust is organic. The organic dust varies greatly in character; it may contain pollen grains, scales of skin, grains of starch, pus cells, rotifers, wings of insects, dung, and various micro-organisms.

A few vegetable dusts, such as cotton dust, or "flue," and flax dust, or "ponce," are irritating and harmful. In 1892 the death-rate from phthisis in Belfast linen factories was 41·1 per thousand, as compared with 14·6 for the whole of England and Wales, and 21·6 for all Ireland.

The following table, compiled by Harrington from Hirt, is of great interest:—

	Pneumonia.	Phthisis.	Digestive Disorders.
Workers in metallic dust	17·4	28·0	17·8
" mineral dust	5·9	25·2	16·6
" vegetable dust	9·4	13·3	15·7
" animal dust	7·7	20·8	20·2
" mixed dust	6·0	22·6	15·2
" non-dusty trades ...	4·6	11·1	16·0

It is chiefly the presence of germs and the seeds of germs that render organic dust dangerous. Long before germs were discovered by Leuwenhoek they were suspected, and in 1859 Schroeder wrote: "It must be admitted that fresh air contains an active substance which provokes the phenomena of alcoholic fermentation and putrefaction, a substance which heat destroys and cotton-wool arrests. Must this active substance be regarded as formed of organised microscopic germs disseminated in the air?" But not till Pasteur and Tyndall, and others proved their responsibility for fermentation and putrefaction, was their aërial ubiquity established. So plentiful, then, were they found to be, that Pouchet remarked sceptically that the air must be dense as iron with them. So universal are they that no sweet liquid left uncovered can long escape fermentation, and all organic matter soon undergoes putrefaction, and so small are they that the evaporation of a single drop of putrid infusion might conceivably permit the launch into the atmosphere of more than one thousand million organisms.

Germs are not found in all air: the air of uninhabited regions may be quite free from germs, and the higher we ascend the more scarce do they become; but in the air of towns and of inhabited buildings (where the air is in motion) germs are always to be found, and we have thus to consider dust not only as the sun-reflector and rain-bringer, but also as the messenger of Death. In the dust there may lurk typhoid, and cholera, and tuberculosis, and gangrene, and lockjaw, and leprosy, and death and disease in many other terrible forms. A little invisible dust floating in the air may sow pestilence and death over a whole continent, and may destroy a whole people, and Tyndall truly says that "all the havoc of war ten times multiplied would be evanescent if compared with the ravages due to atmospheric dust."

Many scientists have investigated the germs in the air and dust. Let us look for a moment at some of the results of their investigations.

As long ago as 1875 Tyndall made some rough experiments. He exposed about a thousand tubes of infusion to the air of London by placing them at various points in the Royal Institution, on the roof of his house, in his bedroom, in an upper kitchen, in his study, in the theatre, &c., &c. "All were smitten with putrefaction, and with its invariable associate, *Bacteria*." Similar tubes exposed to the air of the country likewise putrefied. On the other hand, 27 flasks exposed to air on the Aletsch Glacier (8,000 feet) showed no signs of putrefaction.

About the same time Pasteur made an interesting comparative experiment. He prepared sixty flasks of clear broth. Twenty of these were exposed to air at the foot of the heights which form the first plateau of the Jura, twenty to air on a peak of the Jura 850 metres above sea-level, and twenty to air near the Mer de Glace 2,000 metres above sea-level. Of the first twenty, eight contained micro-organisms; of the second, twenty-five; and of the last twenty, only one. He found, further, that all flasks exposed to the air of the inn near the Mer de Glace quickly putrefied.

A few years later Pierre Miguel, of the Observatory of Montsouris, began to count the spores, microbes, fungi in air in various localities, and his results are still classical. In dry, dusty weather he found the number of bacteria in Paris air might rise to 150 per cubic foot; while after wind and rain only 6 per cubic foot could be detected. On the top of high buildings he found few bacteria. Thus, on the top of the Pantheon he found only 1½ bacteria per cubic foot, while in the streets there were about 12. Indoors, in dirty rooms and inhabited places, he found micro-organisms much more plentiful—about eight times more plentiful than in the open air. Thus, in a neglected hospital he found 3,170 in the cubic foot. In a gram of the dust of his laboratory he found 750,000 micro-organisms, and in a gram of dust in a room in Paris he found 2,100,000. He also made the interesting observation that the micro-organisms in the air of Montsouris were greatly increased if the wind blew across Paris. His results will best be shown by quoting a few of his tables.

	Bacteria per Cubic Metre.
Summit of Pantheon	28
Peak of Monsouris	45
Fourth Arrondissement...	462

BACTERIA FOUND IN CUBIC METRE OF AIR.

	Rue de Rivoli.			Montsouris.
	1880–81.	1881–82.	Average.	Average.
October	920	1,070	990	128
November	750	780	760	88
December	540	530	535	51
January	470	160	320	54
February	330	200	265	58
March	750	560	655	55
April	970	850	910	54
May...	1,000	970	985	60
June...	1,540	300	920	57
July...	1,400	420	910	116
August	960	710	835	96
September	990	840	915	89
Average ...	880	620	750	75

BACTERIA FOUND IN CUBIC METRE OF AIR.

	Hospital de la Pitié.		Fourth Arrondissement.
	Salle Michen.	Salle Lisfranc.	
	Hommes.	Femmes.	
March, 1881 ...	11,100	10,700	750
April	10,000	10,200	970
May	10,000	11,400	1,000
June	4,500	5,700	1,540
July	5,800	7,000	1,400
August	5,540	6,600	960
September ...	10,500	8,400	990
October	12,400	12,700	1,070
November ...	15,000	15,600	780
December ...	21,300	28,900	525
January, 1882 ...	16,100	12,800	160
February	14,400	11,100	200
March	14,800	10,550	560
April	11,120	7,560	850
May	6,300	5,930	970
Average ...	11,100	11,100	850

Flügge considers that on the average there are about one hundred micro-organisms to a cubic metre of city air—an average evidently below that of Paris.

It will be noticed how much fewer are the microbes in summer when the windows are open.

In a paper communicated to the Royal Society in 1886 Percy Frankland gives the results of further interesting investigations. We have space here to give only a few excerpts from his tables.

TABLE I.—Roof of Science Schools, South Kensington Museum.

Date, 1886.	Conditions of Experiment.	Total Number of Micro-organisms Falling per Square Foot per Minute.
March 16th	Wind north-west, moderate, ground dry and frosty. 11.50 a.m. to 12.30 p.m. Temperature 3° C. Four dishes exposed on west parapet.	101 109 83 101
March 31st	Wind south-west by west, intermittent and variable. Sun shining greater part of time; ground wet. Wind increased considerably at 1.45 p.m. Temperature 12·5° to 11° C.	1 to 1.10 p.m. 851 1.20 to 1.35 p.m. 215 1.38 to 1.58 p.m. 803 1.40 to 1.50 p.m. 1,302
May 12th	Continuous rain previous day till morning of experiment, ground and surroundings thoroughly wet. Wind east, fairly strong. Tube pointed north-west. 4.12 p.m. Temperature 12° C.	66 60 61
May 25th	Wind south-west, moderate. Pavement dry, but heavy rain all previous day and part of night. 6.10 p.m. Temperature 13° C.	130

TABLE II.—EXPERIMENTS IN COUNTRY PLACES.

Place and Date.	Conditions of Experiment.	Total Number Found in 10 Litres.	Total Number Falling per Cubic Foot per Minute.
Edge of Reigate Hill, about 700 feet, February 7, 1886.	Wind east in gusts, but not very strong; ground partially hard with frost and partially moist; occasional sunshine. Noon. Temperature 1° C.	2	15
Lawn in Garden on Reigate Hill, May 23, 1886.	Wind south-west, very gentle 6 to 7 p.m. Temperature 5° C.	25	31
Garden near Norwich, April 23, 1886.	Wind east, blowing across Norwich, less strong than in morning; sunshine. Temperature 12° C. 4 to 5 p.m.	—	252
Mousehold Heath, Norwich, April 27, 1886.	Wind east, conditions much as in previous experiment. 11 to 12 a.m.; sunshine.	5	16
Garden near Norwich, April 28, 1886.	Wind east, slight, sunshine. Temperature 12° C. Noon.	31	386

TABLE III.—EXPERIMENTS IN OPEN PLACES IN LONDON.

Place and Date.	Conditions of Experiment.	Total Number Found in 10 Litres.	Total Number Falling per Cubic Foot per Minute.
Kensington Gardens, near Round Pond, April 1, 1886.	East side of Round Pond. Wind south-west by west, fairly strong, blowing across grass; grass and ground damp; streets dry, sunshine. 12 to 2 p.m. Temperature 12° C.	21	88
Hyde Park, May 18, 1886.	Grass in hollow. Wind south-west, fairly strong. 5 p.m. Temperature 16° C. to 14·5° C.	48	207
Primrose Hill, top, May 19, 1886.	Ground very wet; grass. Wind south-east, fairly strong. 2 p.m. Temperature 13·5° C.	9	12
Primrose Hill, bottom, May 19, 1886.	Similar. Wind not so strong as above. 3 p.m. Temperature 13·5° C.	24	57

TABLE IV.—EXPERIMENTS AT DIFFERENT ALTITUDES.

Place and Date.	Conditions of Experiment.	Total Number Found in 10 Litres.	Total Number Falling per Cubic Foot per Minute.
Cathedral Spire, Norwich, April 26, 1886.	Height about 300 feet. Wind east, fairly strong. Tube projecting from south-east window at top of spire. 5 p.m.	7	49
Cathedral Close, Norwich, April 26, 1886.	Wind east, moderate. Gravel space in front of south transept of Cathedral. Ground dry; sunshine. Temperature 9° C. 12 to 1 p.m.	18	354
Stone Gallery, St. Paul's, May 29, 1886.	Wind south-west, strong. 2 p.m. Temperature 13° C.	23	226
Churchyard, St. Paul's, May 29, 1886.	Sunshine. 3 p.m. Temperature 13·5° to 14° C.	41	341

TABLE V.—INDOOR EXPERIMENTS.

Place and Date.	Conditions of Experiment.	Total Number Found in 10 Litres.	Total Number Falling per Cubic Foot per Minute.
Drawing-room before children's dance, February 6, 1886.	Room almost empty. Dishes exposed 4 feet above ground.	—	44 50
Ditto during dancing, February 6, 1886.	About twenty children dancing, otherwise conditions as above.	—	400 300
Railway carriage, April 28, 1886.	Four passengers; one window quite open, one closed. Dish exposed by open window 3 feet above ground.	—	395
Ditto	Ten passengers; one window open 4 inches, one window closed. Dish exposed by closed window.	—	2,120
Hospital for Consumption, Brompton, May 27, 1886.	"Richmond" Ward. Eight persons in bed. 9 p.m. Temperature 16·5°. Dish exposed on chair on ground.	42	44
Ditto	"Richmond" Ward. Eight persons in room, some moving about. 4.20 p.m. Temperature 16° C. Dish exposed on chair set on bed.	130	130

These figures are very instructive, and it will be noticed, among other things, that the micro-organisms are fewer in air at a height, and that they are increased in number when people are crowded together, or when they move about in enclosed spaces.

The relationship between height and number is well established.

Dr. Jean Binot did not find a single microbe in 100 litres of outside air, taken at the summit of Mont Blanc; and he found a progressive decrease in the number of microbes as the height increased. Thus he found—

At Montanvert	49
At the Mer de Glace	23
At the Place de l'Aiguille	14
At the Grand Malet	8
At the Grand Plateau	6
On the Summit	0

Again, Graham Smith found at the top of the Clock Tower of the Houses of Parliament in London only one-third of the number at ground-level.

In 1887 Carnelly, Haldane, and Anderson made some very important analyses of samples of indoor air.

Their investigation, reported in the Transactions of the Royal Society, 1887, is full of interesting results, but here we can give only a few of their figures.

Perhaps the most interesting analyses they made were the analyses of the air in artisans' bedrooms between 12.30 a.m. and 4.30 a.m. These analyses showed that bacteria increased as cubic space diminished. The following table gives a synopsis of their results:—

Cubic Space per Person.	No. of Houses.	Temperature.	Carbonic Acid.	Organic Matter.	Micro-organisms per Litre.	Bacteria.	Moulds.
100–180	14	55	11·5	15·1	80	78	1·8
180–260	18	54	10·7	15·1	49	47	1·5
260–340	6	53	10·3	11·8	32	31	0·7
340–500	4	57	9·2	8·4	42	40	2·1
500–1,000	6	54	8·6	5·6	6	6	0
1,000–2,500	8	53	6·7	3·9	9·1	8·5	0·7
2,500–4,000	4	57	7·9	5·0	13·1	12·8	0·4

The air of schools was also investigated with the following results :—

SCHOOLS.

	Naturally Ventilated.				Mechanically Ventilated.			
	No. of Cases.	Lowest.	Highest.	Average.	Average.	Lowest.	Highest.	No. of Cases.
Total micro-organisms	35	8	600	152	16·58	0	58	18
Bacteria ...	28	8	600	151	16·0	0	56	18
Moulds ...	28	0	4	1·1	0·58	0	2	18

With reference to their examination of school air they write : "When we come to consider that the children who attend average Board schools for six hours a day are during that time subjected to an atmosphere containing on an average nearly 19 volumes of carbonic acid per 10,000, and a very large proportion of organic matter, and no less than 152 organisms at least per litre, we need not be surprised at the unhealthy appearance of very many of these children. It must be borne in mind that many of them are exposed for nine hours more to an atmosphere, which as we have shown above (in first table quoted), is about five times as impure as that of an ordinary bedroom in a middle-class house."

An examination of mills showed that in mills bacteria were still more plentiful.

JUTE AND TOW MILLS.

(*Six Rooms examined.*)

	Lowest.	Highest.	Average.
Total micro-organisms	4	600	160
Bacteria	4	586	114
Moulds	0	600	125

In Dundee Hospital only two or three micro-organisms per litre were found.

Of course, the number of organisms in the air in a confined space must depend to a large extent on the movement of dust. If the air be quite still, all the dust and all the micro-organisms settle after a time. Pasteur found accordingly that the air in an underground cellar contained no micro-organisms, and the same is the case in coal-mines. In the underground railways there are fewer germs than in the outside air.

On the other hand, violent stirring of the dust soon scatters the microbes. Thus the observers, whose figures we have just quoted, found that the number of bacteria in a litre of air in the High School, Dundee, could be raised from 10 to 150 simply by the boys stamping the floor; and other investigators have found that the air of a ballroom contains much above the normal quantity of dust and micro-organisms.

The importance of clean, dustless houses suggested by the above facts is proved in the following figures :—

		No. of Cases.	Average Space per Person.	Average Carbonic Acid per 10,000.	Average Organic Matter.	Average Micro-organisms per Litre.
One-roomed houses	Clean	1	295	8·0	13·1	18
	Dirty	7	200	9·9	18·1	41
	Dirtier	13	221	10·7	13·5	49
	Very dirty	6	220	11·0	15·1	93
Two-roomed	Very clean	2	273	12·2	10·8	10
	Clean	4	264	9·3	7·7	22
	Dirty	7	233	9·4	11·2	69
Naturally Ventilated Board Schools	Cleaner	12	167	19·7	18·1	91
	Average Cleanliness	12	166	14·2	16·2	125
	Dirtier	12	191	22·5	15·2	198
Mechanically Ventilated schools and college	Cleanest	7	194	12·5	12·7	3
	Clean	11	155	12·8	8·3	16
	Less Clean	4	152	10·8	9·8	30

In 1901–1902 Haldane and Osborne made 39 analyses of workrooms—chiefly printers', bookbinders', tailors', and milliners' workrooms—and found an average of 8·0 bacteria and 2·2 moulds per litre of air.

One or two more analyses of dust and air may be quoted. A few years ago Sir James Crichton Browne analysed the dust from the top of a wardrobe and found—

	Per Cent.
Moisture	4·4
Organic matter (chiefly organised)	52·6
Silica and insoluble silicates	21
Oxide of iron and alumina	9·7
Lime (CaO)	6·2
Carbonic acid with traces of sulphuric and phosphoric acid	6·1
	100

"Under the microscope," he states, "the dust is seen to consist of inorganic and organic material. The inorganic matter is mostly amorphous, while the organic is for the most part organised.

"Among the commonest constituents are vegetable and animal fibres derived from fabrics, such as linen, cotton, and wool. Something resembling jute fibre is also seen.

"Among the most interesting constituents are squamous epithelical cells from the skin, and small round cells, both of which are fairly numerous. Food materials are represented by starch granules, and there are certain organised vegetable materials, among which a few pollen spores can be identified. The dust would make an excellent manure, but as an article of toilet is scarcely to be recommended."

In 1902 an interesting analysis of Tube air was made by Dr. T. W. Andrewes. The following figures are taken from an abstract of Andrewes' results given by Dr. G. Newman ("Bacteriology and Public Health"):—

	Time of Day.	Carbon Dioxide per Cent.	No. of Bacteria.	No. of Moulds.
	a.m.			
1. Platform	11.30	0·09	14	13
2. Lift	11.45	0·109	20	19
3. Carriage (smoking)	11.45	0·108	51	10
4. Tunnel	11.45	0·082	10	8
5. Carriage (non-smoking) ...	2.45	0.111	13	14
6. Platform	5.10	0·103	30	11
7. Platform	11.40	0·094	106	6
8. Carriage	11.20	0·134	90	13
9. Tunnel	11.15	0·104	10	4
10. Lift	11.0	0·152	64	9
11. Staircase (passage)	11.0	0·078	13	3
12. Staircase (passage)	11.0	0·102	17	7

In 1903 Dr. Scott Tebb made a similar analysis with results shown in the following table:—

Air of—	Carbon Dioxide per 10,000 Parts.	No. of Micro-organisms per Plate.
The open streets	3·8	459
Platforms in railway tube	7·9	114
Railway carriages in tube	11·6	218

Finally, Dr. Newman's analysis of the air in underground bakehouses may be quoted :—

	Carbonic Acid Gas in Parts per 10,000.	Average No. of Bacteria on each Plate.
Underground bakehouse B	12	800
" " C	17·5	680
" " D	16·9	600
" " E	13·6	600
Above-ground bakehouse Z	4·9	200
Outside air in street	4·5	160

All these analyses show how widely and irregularly micro-organisms are distributed in the air; but micro-organisms are not necessarily harmful, and a mere numerical estimate is of little value. What we wish to know is the number, origin, and distribution of pathogenic germs; and so far, unfortunately, little is known. In a few cases individual microbes have been identified.

In the dust of New York streets were found abundant micro-organisms, including bacilli coli communis. In the air of Nottingham during "goose fair" were found staphylococcus pyogenes aureus and albus, bacillus subtilis, and bacillus coli communis. In railway air Anderson found staphylococcus flavus and albus, micro-coccus candicans, micro-coccus flavus, micro-coccus citreus, micro-coccus lactis, micro-coccus albicans tardissimus, sarcina lutea, sarcina flava, sarcina alba, bacillus luteus, bacillus lactis innocuus, streptothrix Försteri, streptothrix chromogenes, streptothrix albido-flava torula alba, and saccharomyces cerevisiæ—a multitude not quite so formidable as their names, since none are harmful. Andrewes found in the dust of London streets staphylococci, streptothriceæ, and moulds, but no pathogenic species.

In the air of hospital wards at Lille, Delalivesse found bacilli coli, streptococci, and staphylococci; and there can be no doubt that, before the days of Listerism, the air of hospitals was full of the organisms of suppuration. In the dust of railway carriages, tramway cars, and public-houses tubercle bacilli are often found, and the bacillus of lockjaw is found especially in the dust of stable-yards.

The evidence as to the actual distribution of pathogenic germs is meagre; but it seems certain that ordinary outside air contains comparatively few pathogenic micro-organisms, and that, under ordinary conditions of cleanliness and ventilation, they are more abundant indoors. This is just what might be expected. Germs of every sort, as we have seen, are more plentiful indoors: they are brought in by the inhabitants; they float in at the window; and settle on the curtains, and wall-paper, and books, and furniture, and carpets, and clothes, and are easily stirred up by draughts, and by movements of people and things in the room; and among the more numerous germs there is a greater chance of meeting pathogenic ones. Further, any one who is ill and who lives indoors, is likely directly to infect the air. The desirability, therefore, of cleanliness, ventilation, and sunlight is quite obvious, for even as there are fewer microbes and less dust in well ventilated clean rooms, so there will be fewer pathogenic organisms and less risk of infectious disease, whether the microbes come from within or without.

Probably all the infectious diseases (including small-pox, measles, whooping-cough, scarlet fever) are due to microbes, and most are contracted through the medium of the air, which conveys the microbes, either directly or indirectly, to the respiratory or digestive tract. In some cases the air-borne microbes may be conveyed by the air to the victim *viâ* books, or articles of bedding, or clothing, or food; and in other cases, again, they may be conveyed by the air directly from person to person; but however microbes are borne, good ventilation and cleanliness will diminish the risk of contracting microbic diseases.

In dark, dirty, dusty houses, where, as we have seen, microbes are unduly numerous, the microbes of disease may lurk for years, and in such houses all air-borne microbic diseases are especially common and fatal.

This is shown by numerous statistics, such as the following table collated from Körösi's figures:—

IN THE LOWEST CLASS OF ROOM IN BUDA PESTH.

	Increase or Decrease in Percentage Death-rate.
Measles	+159
Whooping-cough	+100
Scarlet fever	− 8
Croup and diphtheria	+ 11
General death-rate	+ 35

The increase in the death-rate from measles and whooping-cough in these cases is due to secondary broncho-pneumonia contracted, no doubt, by microbic dust in the dirty houses, and in one and two-roomed dirty houses a similar high death-rate from similar causes is always found.

Even better-class houses are dusty, ill-ventilated, and microbic. The carpets, and chairs, and curtains, and wall-papers, and books, and ornaments are usually swarming with microbes, and on the tops of the wardrobes there is the accumulated dust of ages. So long as people use dirty wall-papers and dusty carpets, and fill their rooms with unnecessary knick-knacks, they cannot be considered really civilised, and the day will yet come when simplicity, cleanliness, pure air, and sunlight will be more esteemed than all the trappings of modern luxury.

The dusting and sweeping, as usually practised, amount to little more than a redistribution of germs; the germs are flicked from the furniture on to the floor, and then swept from the floor again into the air, and the process called spring-cleaning naturally results in a spring-crop of colds. It is a most barbaric idea that rooms should be cleaned only once a year and ventilated only once a day. They should be furnished in such a way that they can be thoroughly cleaned daily, and built in such a way as to be open to the air all day long and all night long.

All sweeping should be done with moist mops and all dusting with moist dusters; and failing the possibility of this, the old practice of sprinkling tea-leaves has much to recommend it.

Worse even than houses are many public buildings, such as theatres and churches. These are built in such a way that neither air nor light has free entry, and in such a way, too, that thorough cleaning is almost impossible. The dust and germs that enter live securely in dark corners, and every draught that blows carries possible disease into the air.

The dangerousness of air-borne bacteria depends, to a large extent, on their vital resistance to drying, and Dr. Germano has recently endeavoured to make a classification of microbes on this basis. He suggests the following division:—

(*a*) Such bacteria as those of plague, typhoid, cholera, which are killed by drying in a few hours.

(*b*) Such bacteria as those of diphtheria, which stand drying better.

(*c*) Such bacteria as those of consumption, which endure drying for many months.

The dangerousness of air-borne bacteria must also depend to a large extent on their lightness. Neisser found that the bacteria of diphtheria, typhoid, plague, cholera, and pneumonia are incapable of being carried by the air; while the bacteria of anthrax and of tuberculosis are readily carried. Possibly the rapidity with which influenza spreads may be due to the extreme smallness and lightness of its bacillus.

The question has often been debated whether microbes can be given to the air by sewers. The air over sewers is very free from germs, usually not more than two per litre, and these are usually not pathogenic. On the other hand, it seems to be proved that if sewage be splashed, or if a bubble in sewage burst, micro-organisms may be given to the air: and Flügge "has tried to prove that air-currents, having a velocity of 4 metres per second, can remove bacteria from the surfaces of liquids by detaching drops of the liquid itself."

The question has also often been debated as to whether expired air bears germs and solid particles. From what we have already seen of the filtering capacity of the nose and air-tubes, we should expect the air of expiration to be germ-free; and almost germ-free it usually appears to be. In a report to the Smithsonian Institute of Washington upon the composition of expired air, it is concluded that "in ordinary quiet respiration no bacteria, epithelial scales, or dead tissue are contained in expired air." In fact, the effect of breathing, so far as germs and dust are concerned, is to filter the air. Haldane observed that the air of a room contained fewer germs after it had been occupied by people. Strauss, again, counted the bacteria in inspired and expired air, and in one experiment found over twenty thousand bacteria in the expired air and only forty in the inspired.

On the other hand, loud speaking, singing, sneezing, and coughing may ejaculate particles of saliva and mucus with solid particles and germs, and thus the microbes of pulmonary diseases may be sprayed into the air. Flügge, Laschtschenko, Heymann, and others have proved this beyond a doubt. Laschtschenko washed out his mouth with a broth containing *Bacillus prodigiosus*, and found that when he coughed and sneezed the bacteria were ejected and might be demonstrated on culture plates dispersed over the room. Heymann made elaborate experiments, and proved that in coughing germs might be ejected to a distance of over a yard, and that they might be borne by currents of air even behind the person coughing. Heymann also proved that spray-droplets and particles of pulverised sputum were held in suspension in the air for only a short time.

Air Infection in Tuberculosis.—The question of air infection in tuberculosis is so important that it must be separately considered.

Tuberculosis is an infectious disease, and infection may probably be spread in three ways: (*a*) By tuberculous food. (*b*) By dried tubercular sputum. (*c*) By the tubercular spray produced by coughing, &c. With the first we have here no concern, but the last two must be briefly discussed.

(*a*) *Dried Tubercular Sputum.*—It has been proved experimentally by Koch, Cornet, and others that infection may be produced by the inhalation of dried tubercular dust. In his famous experiments of 1898 Cornet scattered dust mixed with pulverised tuberculous matter over a carpet, and having placed some guinea-pigs in the room at varying levels up to 4 feet, he swept the carpet with a stiff broom. He also made a second lot of guinea-pigs inhale tubercular dust. Under these conditions 46 out of 48 guinea-pigs became infected with tuberculosis. Dr. J. H. Hance inoculated 10 guinea-pigs with dust from one of the cottages of the Adirondack Cottage Sanitorium, and 5 of the 10 became tuberculous. The cottage had been occupied by a man who had indulged in promiscuous spitting.

The danger of tuberculous dust must therefore be considerable, for not only may sputum be expectorated on to the floor and walls to dry there, "but," as Koch points out, "a good deal of it dries on bed-linen, articles of clothing, and especially on pocket-handkerchiefs, which even the cleanest of patients cannot help soiling with the dangerous infective material when wiping the mouth after expectoration, and this, too, is subsequently scattered as dust."

Flügge, however, who has made many experiments, does not think that infection by dry sputum is very common, since sputum is very difficult to pulverise, and since particles fine enough to be held in suspension in the air can only be very rarely and sparsely present, and Cornet admits that "it is no easy task to produce a really fine powder which remains suspended in the air for some time."

Still, there is no doubt that there is some danger; and it seems to the writer that the two greatest sources of danger are handkerchiefs and moustaches. Beninde has shown that sputum-stained handkerchiefs if kept in the pocket for a day do not grow dry enough to give up their bacteria to weak currents of air; but handkerchiefs are often kept in the pocket for more than one day; and further the chief danger perhaps lies in this—the pocket is contaminated more and more day by day, and each time the handkerchief is produced it brings forth dried sputum from the pocket.

The danger of the moustache has not so far been properly appreciated, yet it is quite plainly a most efficient sputum pulveriser. Every time the consumptive patient coughs or expectorates his moustache is smeared or sprinkled with sputum. The sputum, thus spread in a thin layer on the hair, is readily dried, and must be very readily thrown off when the moustache is brushed or moved.

(*b*) *Tuberculous Spray.*—As we have mentioned, it has been proved that bacilli can be ejected to a certain distance by coughing, sneezing, and loud speaking; and some authorities are of the opinion that such spray in the air is the most common source of infection. Against this view it must be remembered that such spray is only carried for a few feet, that it soon falls, and that it contains a comparatively small number of tubercle bacilli. B. Fränkel made "a number of consumptives wear masks for twenty-four hours at a time, and with 219 of these masks he caught 2,600 tubercle bacilli in 32 days"—a very small number compared with 7,200,000,000 bacilli which one consumptive may discharge in one day in his expectoration.

"Whatever," says Newsholme ("The Prevention of Tuberculosis") "be the proportionate share of infective dust and infective spray, it is certain that dust plays an important part in spreading tuberculosis. There is abundant evidence that the dust in the vicinity of consumptives contains frequently, while that from other localities seldom contains, tubercle bacilli."

In 1888 Cornet inoculated guinea-pigs with the dust obtained from the walls and floors of sick-rooms occupied by consumptives, with the following results as given by Newsholme (*loc. cit.*):—

"In 7 hospitals 38 tests were made, 94 animals being inoculated with dust. Of this number 52 died from diseases other than tuberculosis, 22 remained healthy, and 13, or 39·4 per cent., became tuberculous. In 2 prisons 5 tests were made on 14 animals, and with a negative result as to tuberculosis. In the dwellings and work-places of consumptives 62 tests were made, 170 animals being employed, of whom 91 died from other diseases, 45 remained healthy, and 34, or 20 per cent., became tuberculous. In a surgical ward 3 tests were made, 8 animals being employed in each instance, with a negative result as to tuberculosis. In certain streets 14 tests were made; 41 animals were employed, and here again a negative result as to tuberculosis was consistently obtained.

"The dust of rooms occupied by consumptives was regularly virulent in the instances in which the patient had been in the habit of spitting into his handkerchief or on the floor. It showed no evidence of virulence when the spittoon or spit-bottle had been regularly used. Cornet also found virulent tubercle bacilli in the dust of a room in which a consumptive had died six weeks previously."

Dr. H. Coates made similar experiments. He took samples of dust from the floor, walls, mantelpieces, &c., of forty-three houses and inoculated guinea-pigs. Twenty-three of the houses were dirty and were inhabited by consumptives who took no precautions in the disposition of their sputum, but spat on to the floor or into pocket-handkerchiefs. The dust of these houses was found infectious in 66·6 per cent. of cases.

Ten of the houses were clean and inhabited by consumptives who were not sufficiently careful in the disposal of their sputum. The dust of these houses was found infectious in 50 per cent. of cases.

Ten of the houses were dirty, but contained no consumptives. The dust of these houses was found non-infectious.

In many instances dust taken from railway carriages and tramway cars has been found infectious.

The risk, therefore, of air infection by cases of pulmonary tuberculosis is considerable if the house of the patient be dusty and if proper precautions be not taken; but on the other hand the risk of infection must not be exaggerated, for even in dirty infected houses the particles of expectoration tend to gravitate to the floor and to remain there. Great or small, however, risk there is where dust there is, and it is absolutely essential that where there are consumptives every precaution should be taken to dispose safely of the sputum and to prevent the collection of dust.

Epidemic Diarrhœa and Air-infection.—Epidemic diarrhœa is probably a microbic disease, and the microbes probably grow in the soil when the soil reaches a certain temperature, and are carried by the air and deposited in the milk on which the infants are fed. It seems very possible that in some cases the microbes are carried by flies. Breast-fed children are almost exempt from the disease.

The solution of the whole dust problem, so far as solution can be found, is ventilation, sunlight, and cleanliness. The question of the dust raised by motor cars will require special legislation; but there can be no doubt that the clouds of dust they raise both in town and country, but especially in the country, are a danger to the public health and a constant source of sore throats and sore eyes.

CHAPTER XII

VENTILATION

VENTILATION is the removal of impurities from the air of confined spaces by diffusion, and by the circulation of air. Though, as we have seen, carbon dioxide is probably not the most mischievous of the constituents of vitiated air and though its significance varies, yet the amount of carbon dioxide in air has been generally adopted as the most convenient index of the total conditions which are usually prejudicial to health and comfort, and the efficiency of ventilation is usually estimated by an estimation of the carbon dioxide.

Now the first question is, What percentage of carbon dioxide must be considered to indicate undue vitiation—what is the *limit of permissible impurity?*

As long ago as 1858 Pettenkofer proposed 10 volumes in 10,000 as the limit for inhabited rooms. In 1875 De Chaumont finding that an unpleasant smell was usually perceptible in air vitiated by respiration containing 6 volumes of carbon dioxide in 10,000, fixed 6 volumes in 10,000 as the limit, and for many years his figure was accepted. De Chaumont's conclusions, however, were based on an examination of the air of barracks, and it has been found that in rooms "where the standard of personal cleanliness among the inmates is higher" the percentage of carbon dioxide may rise higher before any smell becomes perceptible.

In 1887 Carnelly, Anderson, and Haldane "concluded that for the very crowded elementary schools of this country a lower limit than 13 volumes could not for practical and financial reasons be fixed."

Finally, in 1902 the Departmental Committee (Haldane and Osborne) appointed to inquire into the ventilation of factories and workshops made the following recommendations:—

"1. That in exercise of the powers conferred on the Secretary of State, by Section 7 of the Factory Act of 1901, such a standard of ventilation should be prescribed for all classes of factories and workshops not otherwise specially dealt with, that the proportion of carbonic acid in the air at about the breathing level, and away from the immediate influence of any special source of contamination, such as a person or light, shall not (except on very foggy days, when no tests should be made, on account of the vitiated state of the outside air) rise during daylight, or after dark when only electric light is used, beyond 12 volumes of carbonic acid per 10,000 of air, and that when gas or oil is used for lighting the proportion shall not exceed 20 volumes after dark or before the first hour after daylight; the only exception to this rule to be in cases where the extra carbonic acid is produced in other ways than by respiration or combustion, as in breweries, &c.

"2. That in the case of cotton-cloth factories with artificially humidified air the occupier should have the option of coming under the regulation just mentioned, instead of remaining under the existing regulation.

"3. That Inspectors of Factories should inform employers of the results of any official analyses of the air in their factories or workshops, should give notice that the ventilation is deficient to any employer in whose factory or workshop the above proportions have been found to be exceeded, and at the same time supply, so far as practicable, information as to the nature of any defect noticed ; and that legal proceedings should not be taken against an employer unless, after a reasonable interval following such notice, the stated proportion is found, on an average of two or more samples taken in different parts of the room, to be again exceeded by one volume or more, and he is unable to show that he has taken measures reasonably caculated to secure the requisite ventilation.

"4. That arrangements be made by the Factory Department of the Home Office for the analysis by a specially qualified person or persons of samples of air collected by Inspectors, and that any analysis on which a prosecution immediately depends shall have been performed by such qualified person or persons."

So far, however, no legal standard has been fixed except in the case of the artificially humidified air of cotton-cloth weaving sheds, where a limit of 9 volumes—considered somewhat stringent by Haldane and Osborne—has been fixed.

Probably, about 10 volumes in 10,000 allows a fair margin of safety ; and certainly, so far as the carbon dioxide itself is concerned, many more volumes might be permitted without fear.

Taking, then, 10 volumes in 10,000 as the limit of permissible impurity, the question next arises, How can this limit be kept?

At first sight it might be thought that the carbon dioxide percentage could be kept most easily low by providing plenty of air-space, and plenty of air therefore, to dilute impurities, and legislative attempts have been made to ensure pure air by enforcing the provision of so much cubic space per head. The following table of attempts in this direction is given by Parkes and Kenwood:—

	Minimum Space per Head in Cubic Feet.	Authority.
Common lodging-houses (sleeping rooms)	300	Local Government Board (Model Bye-laws)
Registered lodging-houses—		
Rooms occupied by day and night	400	Ditto
Rooms occupied by night only	300	Ditto
Non-textile workrooms	250	Factory Act, 1901
Non-textile workrooms during overtime	400	Ditto
Underground bakehouses ...	500	Order under Factory Act, 1901
Above-ground bakehouses where night work is carried on by artificial light other than electric light	400 cubic feet between 9 p.m. and 6 a.m.	Ditto
Army barracks	600	British Army Regulations.
Army hospital wards	1,200	Ditto
Public elementary schools ...	80	Education Department
London County Council Schools	130	London County Council
Canal boats (persons over 12 years)	60	Local Government Board Regulations under the Canal Boat Act, 1877
Canal boats (persons under 12 years)	40	
Seamen's cabins	72	Merchant Shipping Act
Cows in cowsheds	800	Local Government Board Model Regulations under the Dairies, Cowsheds, and Milkshops Order

A little consideration, however, will show that such regulation of space is by itself of little value. Unless there be movement of air, space alone is futile. However large the space may be the air will become impure unless fresh air circulates through it, and however small the space the air may be kept pure by sufficient circulation.

Let us look for a moment at the manner in which carbon dioxide accumulates in the air.

The carbon dioxide in normal air amounts to ·03 per cent. Expired air, on the other hand, contains more than a hundred times as much—about 4 per cent.—and a man during hours of activity produces about a cubic foot of carbon dioxide per hour. Thus, breathing in any confined space will soon increase the carbon dioxide.

Suppose, for instance, a man be given 1,000 cubic feet of air per hour. The air has ·3 of a cubic foot of carbon dioxide of its own, and during each hour the man's breathing will add a cubic foot of the gas. Thus at the end of the first hour there will be 1·3 cubic feet of carbon dioxide in the 1,000 cubic feet of air, or 13 parts in 10,000; at the end of the second hour there will be 2·3 cubic feet of carbon dioxide in the air, or 23 parts in 10,000; and at the end of the eighth hour 8·3 cubic feet of carbon dioxide in the air, or 83 parts in 10,000.

Suppose that the man were given only 250 cubic feet of air, then at the end of an hour there would be 43 parts in 10,000 of carbon dioxide, and at the end of eight hours the air would be so foul that candles and lamps would cease to burn, and the man would pant for breath, and probably suffer from headache and sickness.

But respiration is not the only source of carbon dioxide in confined places. As we have seen, all illuminants except electric light produce carbon dioxide, and a single gas-jet may be as productive as eight men.

If, then, a man were made to share 1,000 cubic feet of air with a couple of flaring iron batswing gas-jets, he would very soon find the air intolerably vitiated.

Of course such conditions of absolute stagnation of air are not found in real life; but even under the conditions of real life it is easy to see that it is the *circulation of air* and not the space that matters. The following excerpts from analyses of air made by Haldane and Osborne (Departmental Committee to Inquire into the Ventilation of Factories and Workshops) will show that carbon dioxide certainly does not decrease *pari passu* with increase in air-space:—

Business of Firm. Place and Date.	Description of Room.			Number of Occupants and Space.		Gas, Oil, or Electric Light.	Date, Time, and Position of Test.	
	Position, Process, &c.	Cubic Contents. Cubic Feet.	Height, Feet.	Number Present.	Space per Person.		Date and Time.	Where Sampled.
Wholesale tailoring, Whitechapel, E., Feb. 22, 1901.	Top floor, fourth (cutting room).	67,500	12½	50	1,350	Gas, 37 jets.	Feb. 22, 1901, 4.32 p.m.	—
Wholesale tailoring, Whitechapel, E., Feb. 22, 1901. Women's factory.	Top floor, fourth (girls' machine room).	21,953	16	63	348	E.L.	Feb. 22, 1901, 3.20 p.m.	—
Army tailoring, Pimlico, April 23, 1901.	Ground floor (women's machine room).	257,936	50	904	285	—	April 23, 1901. 2.50 p.m.	—
Collar factory, Gloucester, Feb. 18, 1902.	First floor (women's machine room).	59,602	15	90	662	52 gas-jets.	Feb. 18, 1902, 5.25 p.m.	Occupied side of room (gas lit 5 minutes).
Tailoring workshop (English), Cheltenham, Feb. 14, 1902.	First floor (women's machine room).	1,570	—	5	314	4 large gas-jets.	Feb. 14, 1902, 7.30 p.m.	ditto
Large Public Hall (provincial), Nov. 14, 1901.	Ground floor.	—	—	—	—	—	Nov. 14, 1901, 9.10 p.m.	—
Fine cotton-spinning mills, Bolton, Jan. 16, 1902.	Third floor.	91,523	—	9	10,169	Gas, 32 jets, and arc light.	Jan. 16, 1902, 5.5 p.m.	Centre of room, 2½ hours later.

Tem-erature at Same Time.	Volumes of CO_2 per 10,000.		Bacteria, &c., per Litre of Air.		Means of Ventilation in Actual Use at Time of Test.	Remarks.
	Inside Room.	Outside Air.	Bacteria.	Moulds.		
63	35·8	3·5 (Estimate).	17	22	Very deficient. Side windows all closed, no opening in roof. Hoist well from below, but no current.	This room was lofty and spacious. Thinly occupied, and no regard was paid to ventilation. Gas-jets were solely depended upon for heating, and had been alight a considerable time. The air was consequently stagnant and impure.
67	9·2	3·5 (Estimate).	8	1	Four windows in roof, partly open; stairs with door open to roof. Hoist from below.	A remarkable feature in the ventilation here was the great volume of air coming up through hoist, calculated to be 6,000 cubic feet per person per hour.
—	4·6	3·5	—	—	Sixteen large windows on each side, each open about 4 feet by 3 feet. Doors open. Enormous head space.	A fine, lofty, well-arranged building, kept very clean. The outside temperature was warm and the conditions dry and calm. Hence all windows open.
—	37·8 38·6	4·6	—	—	Twenty-two fan-lights opened 1½ inches. One gable ventilator.	Light, clean, spacious room, heated by steam-pipes, comfortably warm. The high results are difficult to account for, but probably the ventilators had all been closed to within a few minutes of a test being made, as women were seen to hurriedly open them. Not more than one-half the room was occupied, but the air was equally vitiated on the vacant side.
72	53·2	4·3	—	—	No ventilation, but chimney with fire lit.	A very unsatisfactory workroom. Scarcely clean and very untidy. Air decidedly stuffy and unwholesome. The worst place of its kind visited during the inquiry.
—	44·4 44·4	3·3	—	—	—	More people going out at second test, but still very full. This sample of air was taken at a congested point in the slowly moving crowd.
95 82	56·6 56·3	4·0	—	—	Nil.	From the analysis of April 8th it is evident that the two "little end" rooms were so tight that more than 14 hours were required to effect an average change of the air. For this reason the air would never be pure, even in the early morning.

It will be noticed that the most highly vitiated air found was in a room with an air-space of about 10,000 cubic feet per person, or forty times the legal minimum.

The same fact of the comparative unimportance of air-space as compared with air circulation is shown even more plainly in the following *résumé* of their results :—

Average cubic feet per person	233	339	496	760	1,227	1,689	2,906	9,404
Volumes of CO_2 per 10,000—								
Daylight or electric light	11·4	10·6	9·7	10·2	9·2	9·0	7·1	12·8
Gaslight or lamplight	20·1	13·6	14·0	13·8	17·4	19·0	17·8	26·3
Number of rooms examined—								
Daylight or electric light	36	33	28	27	27	25	24	25
Gaslight or lamplight	14	8	15	18	14	9	5	12

More striking still is an instance related by Mosso. Mosso tells how in the Regina Margherita Hut forty-five persons were herded together with barely 1 *cubic metre* of air per head. "There were," he says, "forty-five persons altogether, and these had barely 1 cubic metre of air each. Nominally there were 1·29 cubic metres, but we must deduct the volume of each person's body, that of the furniture in the hut, of the provisions, and especially of the fuel. The hut being plated over with copper sheets, of which the joints are hermetically closed so as to prevent the entrance of snow between the planks, the cubic measurement of air for each person may be considered accurate. There was no other opening for ventilation except the windows, which remained off the latch, and the two stove-pipes, which kept up the necessary draught."

Seeing, then, that cubic space per head is no gauge or guarantee of the purity of air, attempts have been made to standardise the ventilation of air—to supply *so much air per head by hour* as will keep the percentage of carbon dioxide below the danger-point.

The amount of air required per head per hour to keep the carbon dioxide below any point is easily found by the equation $D = \frac{E}{R}$ where E = amount in cubic feet, of carbon dioxide produced; R = the limit of permissible impurity per cubic foot, and D = the volume in cubic feet of air required hourly to keep the percentage of carbon dioxide below the limit.

Suppose, for instance, we wish to know how much air must be supplied to a man per hour, who is producing 1 cubic foot of carbon dioxide per hour, in order that the carbon dioxide added to the air may not rise above 2 parts in 10,000.

$$D = \frac{1}{\cdot 0002} = 5{,}000 \text{ cubic feet.}$$

Suppose, again, we wish to know how much air must be supplied to a man per hour who is producing ·6 cubic foot of carbon dioxide per hour, in order that the carbon dioxide added to the air may not rise above 2 parts in 10,000.

$$D = \frac{6}{\cdot 0002} = 3{,}000 \text{ cubic feet.}$$

This last equation represents the figures usually assumed by experts in ventilation; and 3,000 cubic feet of air per head per hour is the amount that is usually considered necessary.

Accepting this estimate, we see that a room with a capacity of 3,000 cubic feet must have its air changed once an hour, and that a room with a capacity of 300 cubic feet must have its air changed ten times. During the first hour rather less than the 3,000 cubic feet will be required, as shown in the following table by Parkes:—

Amount of Cubic Space (Breathing Space) for one Man in Cubic Feet.	Ratio per 1,000 of Carbon Dioxide from Respiration at the end of One Hour if there has been no Change of Air.	Amount of Air necessary to Dilute to Standard of ·2 or including the Initial Carbon Dioxide, of ·6 per 100 Volumes during the first Hour.	Amount necessary to Dilute to the given Standard every Hour after the first.
100	6·00	2,900	3,000
200	3·00	2,800	3,000
300	2·00	2,700	3,000
400	1·50	2,600	3,000
500	1·20	2,500	3,000
600	1·00	2,400	3,000
700	0·85	2,300	3,000
800	0·75	2,200	3,000
900	0·66	2,100	3,000
1,000	0·60	2,000	3,000

Where the Local Government Board prescribes 300 or 400 cubic feet of space per head in lodging-houses it ought also to prescribe that the air should be changed ten or twenty times an hour—a prescription, however, under ordinary circumstances quite impracticable.

Pettenkofer showed "that with the aid of delicate apparatus and mechanical power, about 2,500 cubic feet can be passed without draughts through a space of 424 cubic feet in an hour"; but how to pass 3,000 cubic feet per hour through 300 or 400 cubic feet of space in a poor man's room is a problem still to be solved. Only in large rooms—much larger than the ordinary inhabited rooms—can 300 cubic feet per head be comfortably and conveniently renewed as often as is requisite, and 300 or 400 cubic feet air-space in a common lodging-house may mean anything in the way of impure air. As things are at present matters are most unsatisfactory, for 300 or 400 cubic feet of space per head is not enough, "nor can one successfully insist upon any rule that each person must have at least 1,000 cubic feet of air with renewal of the contained air once in twenty minutes, for to do so is to urge in the case of the poor of large cities an impossibility, since space is costly, and with ventilation to the proper extent is beyond their means." And though in large buildings, such as theatres and churches, it *might* be quite possible to change the air about ten times an hour, yet in such buildings not nearly so much as 300 cubic feet per head is given, and so not even a change of the air ten times an hour would suffice to keep the air pure.

Thus the practical side of ventilation is beset with difficulties.

Let us now see what circulation of air takes place in rooms and buildings under natural conditions, and how the circulation can be assisted by artificial means.

Natural Ventilation.

(*a*) *Diffusion.*—Any vitiated indoor air tends to purify itself by diffusion. If there be excess of carbon dioxide in indoor air it tends to diffuse away into the outside air. If there be a deficiency of oxygen in indoor air oxygen from the outside air will diffuse in. And so with other gases. Diffusion is a constant but very slow process, and the rate of diffusion of gases varies inversely as the square roots of their densities.

(*b*) *Thermal Circulation.*—Any portion of air heated, expands, and if it be surrounded by air cooler than itself it rises; and any portion of air cooled, contracts, and if it be surrounded by air warmer than itself it descends. Now in a room under ordinary conditions the air is unequally heated and cooled, and so ascending and descending currents of air are produced. The heat of living bodies, the heat from gas-jets and fires, the heat from different variously heated bodies, the heat of the lungs, of sun through the window, &c., all communicate heat to an inhabited room and the air accordingly circulates, and as a whole expands and becomes lighter. The air becomes lighter too (even apart from the heat) through the moisture imparted to it by the skin and by the processes of respiration and combustion. The result is that the lighter warmer air tends to escape from the room, both on account of its own expansion and because it is forced out by the heavier colder air.

This is a much more potent means of ventilation than diffusion, for the heated air and the cold air flow out and in spite of every obstacle: they flow through the crevices in doors and windows, through flues, even through plaster and mortar and bricks.

Märker and Schultze, in their researches on the spontaneous ventilation of stables, found that the following spontaneous ventilation occurred per hour over 1 square yard of free wall at 9·5° F. difference of temperature.

With walls of sandstone	4·7	cubic	feet
Quarried Limestone	6·5	,,	,,
Brick	7·9	,,	,,
Tufaceous Limestone	10·1	,,	,,
Mud	14·4	,,	,,

The passage of air through invisible crevices is a much more important means of ventilation than might be thought. Pettenkofer showed that when all visible chinks were closed in a room the rate of ventilation was diminished by only 28 per cent. as compared with the rate when the doors were closed in the ordinary way. Mr. Putnam, experimenting with a small room found similar free ventilation through invisible pores. The room he experimented with was about 5 metres square and 3·6 metres high with plastered walls and ceiling, and having five windows, two doors, and a fireplace. "A flue 10 metres long, from a basement furnace, furnished the rooms with hot air. The windows and doors were first made as tight as possible with rubber mouldings. The fireplace was then closed by drawing the damper and passing water over the cracks. The brick back and jambs were oiled to render them impervious. All the woodwork was thoroughly oiled and shellacked. A good fire was lighted in the furnace, and the register opened into the room, all doors and windows being closed and locked, and the keyholes stopped up. The hot air entered almost as rapidly with the doors closed as when they stood open, and it continued to enter at the rate of 2·5 cubic metres per minute without diminution as long as the experiment was continued. The thermometer stood at 2° C. outside. The entering hot air ranged from 40° to 55° C. The day was March 3, 1880. Other experiments gave the same results. The pressure of the hot air from the register was sufficient only to raise a single piece of cardboard from the register. A portion of the air must have passed through the pores of the materials and the rest through cracks and fissures which escaped detection. On the 5th of March a coat of oil paint was applied to the walls and ceilings, and three coats on the floor, to render them absolutely impervious to air. The escape of air was diminished only about 10 per cent. On the 25th of March all the window-sashes were carefully examined, and all visible cracks at the joints, at the pulleys, cord fastenings, &c., carefully calked and puttied, and the entire room examined, and putty used freely wherever even a suspicion of a crack could be found. The result of all this was a diminution at the utmost of but 20 per cent. in the escape of air, or in other words in the entrance of air through the register. Each experiment was continued during more than an hour. The air entered as freely at the end as at the beginning of the hour, when a volume of air more than equal to the entire capacity of the room had entered it through the register with no visible outlet" (J. Pickering Putnam, "The Open Fireplace in all Ages").

Haldane and Osborne also made numerous experiments to discover the amount of air which may pass through a room unprovided with special openings for ventilation. The following table gives the conditions and results of some of their experiments :—

Description of Room.	Cubic Feet of CO_2 formed per Hour.	Hours since Candles Lighted.	Temperature Centigrade.		Volumes of CO_2 per 10,000.	Hours required for a Volume of Air equal to that of the Room to enter.	Remarks.
			Ins.	Out.			
Room A.—Capacity 1,390 cubic feet, and 9·3 feet high. Bedroom on first floor. Fireplace and one window. One outside wall of brick. Walls and ceiling papered ...	1·29	1·1			8·5	0·8	Flap of fireplace open. Breeze scarcely perceptible throughout experiment
	"	1·1	16·0°	14·2°	10·9		At roof
	"	4·1			13·1	1·1	
	"	4·1			15·1		At roof
	"	5·6			12·6	1·0	Chimney draught =620 cubic feet per hour
	"	5·6			15·7		At roof
Same room ...	1·26	2·7	16·7	9·0	12·1	1·0	Flap open. Very slight breeze
	"	2·7			17·5		At roof
	"	3·7			10·9	0·9	Chimney draught =700 cubic feet per hour
	"	3·7			16·5		At roof
Same room ...	1·40	3·1	17·2	16·7	21·8	2·7	Flap closed. Breeze scarcely perceptible throughout experiment
	"	3·1			22·7		At roof
	"	4·1			26·7	3·4	
	"	4·1			27·1		At roof
	1·36	5·1			26·7	2·9	
	"	5·1			27·2		At roof
	"	6·1			23·2	2·1	
	"	6·1	17·8	13·3	29·1		At roof
	"	9·6			24·6	2·2	
	"	9·6			30·1		At roof
	"	11·6	17·8	10·6	27·2	2·5	
	"	11·6			28·2		At roof
Same room ...	1·31	2·0	17·9	14·5	14·5	1·8	Flap closed, strong wind throughout experiment
	1·31	2·0			16·9		At roof
	1·41	3·0			15·3	1·5	

Description of Room.	Cubic Feet of CO_2 formed per Hour.	Hours since Candles Lighted.	Temperature Centigrade.		Volumes of CO_2 per 10,000.	Hours required for a Volume of Air equal to that of the Room to enter.	Remarks.
			Ins.	Out.			
Same room ...	1·36	1·3	19·4°	13·5°	4·8 4·8	0·2	Fire burning brightly in grate. Slight breeze. Chimney draught = 4,450 cubic feet per hour
	„	1·3			4·8		At roof
	„	2·0	19·4	13·5	6·5	0·4	
	„	2·0			6·5		At roof
	„	3·6	18·8	13·8	7·2	0·4	Fire much lower. Draught = 3,260 cubic feet per hour
	„	3·6			7·2		At roof
Room B.—786 cubic feet. Attic of irregular shape on second floor. One window. Walls papered ...	1·32	1·5	17·8	11·0	20·1	1·8	Wind imperceptible throughout experiment
	„	1·5			28·2		At roof
	„	2·3			24·4	1·8	
	„	2·3			26·0		At roof
	„	3·2	17·8	10·5	22·2	1·2	
	„	3·2			26·9		At roof
Room C.—1,100 cubic feet, 11·5 feet high, and nearly square. A laboratory room on ground floor. One window and one outside wall of sandstone. One inside wall of sandstone, and other two of wood and plaster. Walls not papered. One fixed ventilator at roof. Opening about 24 square inches. Left open through both experiments ...	0·94	0·0	13·5	11·5	3·0		Wind scarcely perceptible
	„	1·0			10·3	2·9	
	„	2·0			11·9	1·3	
	„	3·25			13·4	1·3	
	„	6·0			16·0	1·5	
	„	8·0	13·6	9·0	16·1	1·5	

The results of their experiments in this matter are summarised as follows :—

"Taken as a whole the experiments indicate that in small rooms, provided there is an open chimney, no gas burning, and an air-space of not less than 1,000 cubic feet per person, the ventilation may often be fairly sufficient without open windows or other special means of ventilation. With a good coal fire burning in the grate the ventilation is likely to be fair, even with only 400 cubic feet of air-space per person. The larger the size of the room, however, the greater becomes the need of special openings for ventilation ; and in rooms of over 5,000 cubic feet open windows or special ventilators are nearly always necessary unless the air-space per person is very large or the roof is very permeable to air. In large and crowded rooms it is very difficult to provide adequate ventilation at all times except by the use of fans ; but the observations on the Scotch weaving-shed just referred to show that excellent results can be attained without mechanical ventilation even in a very large room if there is no crowding, and the manufacture is not affected by external variations of atmosphere.

"The difficulty in ventilating crowded rooms, if fairly large without fans is well illustrated by the notoriously bad ventilation of elementary schools. The average proportion of carbonic acid in elementary schools without fan-ventilation was found to be 18·6 during the winter months, with an average of 186 cubic feet of air-space per child, and 15,450 cubic feet per room."

Two points must be specially noticed with regard to thermal ventilation of air : first, that moisture in the walls and on the roof very much impede this circulation, hence in damp weather, quite apart from shut doors and windows, indoor air always feels particularly "stuffy" ; and second, that the larger the room the smaller are its walls, floor, and roof in proportion to its contained air, hence ventilation through floors and roof is most efficient when the room is small.

It must further be noticed that moisture in indoor air also escapes through roof and walls, and that damp roofs and walls prevents this escape even as it prevents the escape of carbon dioxide, hence damp walls keep the indoor air damp and are almost as injurious as damp clothes, or at least, as air-tight clothing.

When doors and windows are shut and a fire burning the principal exit of warm, impure air is through the chimney. In one of Haldane and Osborne's experiments it will be noticed that though the room had only a capacity of 1,390 cubic feet, yet the chimney draught when the fire burned brightly was no less than 4,450 cubic feet per hour. Nor is this an unusual amount. Parkes and Kenwood estimate that in an ordinary medium-sized sitting-room "with an ordinary fire from 10,000 to 15,000 cubic feet of air are drawn up the chimney in an hour, the current being generally from 3 to 6 feet a second." "As ventilating agents," says Notter and Firth, "the best types of open fireplace cause some 2,600 cubic feet of air to pass up the flue per lb. of coal consumed, or the passage of about 18,000 cubic feet up the chimney per hour."

The Local Government Board prescribes that rooms without fireplaces and flues must have "special and adequate means of ventilation by a sufficient aperture or air-shaft, which shall provide an unobstructed sectional area of 100 square inches at least." The sectional area of an ordinary chimney flue is usually 126 square inches.

(*c*) *Perflation and Aspiration.*—Wind plays an important part in ventilation. It acts in two ways. (1) By perflation—by blowing through confined spaces. "Air moving at the rate of 2 miles an hour (which is almost imperceptible) and allowed to pass freely through a room 20 feet broad, will change the air of a room 528 times in one hour." (2) By aspiration. It is rather difficult to explain the aspirating action of wind. It is explained thus by Notter and Firth: "A moving body of air sets in motion all air in its vicinity. It drives air before it, and, at the same time, causes a partial vacuum on either side of its own path, towards which all the air in the vicinity flows at angles more or less approaching right angles. In this way a small current moving at a high velocity will set in motion a large body of air.

"The wind, therefore, blowing over the tops of chimneys, causes a current at right angles to itself up the chimney, and the unequal draught of furnaces is owing in part to the variation in the velocity of the wind. Advantage, therefore, can be taken of this aspirating power of the wind to cause a movement of air up a tube."

Natural ventilation, then, is effected by diffusion, thermal circulation, perflation, and aspiration, and each of these can be assisted in various ways. Diffusion can be facilitated by large cubic space, and by dry and porous walls and roofs. Thermal circulation can be aided by fires and flues and specially made inlets and outlets. Perflation and aspiration can be assisted by open windows, cowled tubes, &c.

Let us look for a moment at the question of inlets and outlets. The ordinary inlets of air are windows and doors and chinks, the ordinary outlets are chimney flues. Open windows, however, recommend themselves to few people, for most people object to the draughts they cause, so special inlets are often made to admit air without draughts. A few of these may be mentioned.

(*a*) Ellison's bricks are bricks with conical perforations, the widened end of the conical opening debouching on the interior of the wall. The holes through the bricks are about $\frac{2}{10}$ of an inch in diameter externally and $1\frac{1}{4}$ inch internally.

Air passing through such bricks is gradually diffused and does not cause a draught. Stables and byres and drill-halls are often ventilated in this way.

(*b*) Tobin's tube consists of a large upright tube, about 5 or 6 feet high, which conducts outside air into the room through the wall.

(*c*) The Sheringham valve is "a small vertical flap door in the wall near the ceiling balanced by a counterpoise, and hinged so as to fall forwards towards the room, it is cased in at the sides and front so that the current can only pass upwards." The size of the internal opening is usually 9 inches by 3 and the area therefore *27* inches.

(*d*) Stevens' Drawer Ventilator is like a drawer lacking its back. It is made to fit into a hole in the wall in such a way that when the drawer is shut the hole is air-tight and when the drawer is open air can enter.

(*e*) Hinckes-Bird Ventilator is made of the opening between two ordinary window-sashes when the lower is raised, and the lower opening closed by means of a specially high sill or by an accurately fitting block of wood.

Rooms may also be ventilated by means of upper window-sashes swinging inwards on a horizontal axis, by holes in the panes and sashes, by louvres, &c.

It must be understood that all these various inlets are intended not to allow *wind* to blow through, but merely to permit efficient thermal circulation without draught. They depend, therefore, for their efficiency on difference between the temperature of the outside and the inside air, and are therefore often most efficient when a fire is burning and when they are least needed. Most of the methods it will be noticed endeavour to divert the incoming current of air upwards; but the advantage of this diversion is very doubtful since the air quickly falls and is probably made to fall just on the heads of the inmates in the room.

All these special air-inlets tend to become foul with dust and soot and they should therefore be guarded by muslin or porous flannel spread over the inlet, and they should also be periodically cleaned.

The area of individual inlets should not exceed 50 square inches and there should be about 24 square inches inlet per head. To avoid a draught the air should not enter faster than 5 feet a second.

The best position for inlets is about 5 feet high, or, if the air be warmed, just above the floor.

Care should be taken that air entering comes from a pure source.

Outlets.—The ordinary outlets are chimney flues. Additional outlet for foul or hot air may be afforded by openings into the chimney flue near the ceiling. The openings should be guarded by Neil Arnott's or Boyle valves—talc plates which allow the air to pass into the flue, but prevent reflux of smoke. Still better outlet ventilation may be arranged by building a shaft either round the chimney flue or against one side of it with an inlet near the ceiling and an outlet on a level with the top of the chimneys. The heat of the flue heats the air in the shaft and causes an ascending outward current. On the same principle outlet pipes from the higher parts of the room may be carried upwards along the flue.

Gas heat can also be utilised for ventilation purposes by placing a bell-cover or glass globe over the gas-lights and conveying the heated air thence to the outer air by means of ascending tubes. McKinnell's Ventilator combines both inlet and outlet. It consists of a tube within a tube leading from the ceiling of the room to the outer air. The area of the inner tube, and of the ring of outer tube encircling it are equal. The inner tube is the outlet tube since the temperature of the air in it is kept higher than the temperature of the air between it and the outside tube. It projects above and below the outside tube, which is the inlet tube. Both tubes are closed by valves. The gas-burners or lamps used to light the room are put immediately under the outlet tube. An advantage of this method is that the entering air is slightly warmer. There should be a cover or cowl over the outlet tube to protect it from wind and rain.

Pott's Ventilator also combines outlet and inlet. It consists of "a hollow metallic perforated cornice divided into an upper and lower half by means of a horizontal plate. Pure air enters the room through the lower half which communicates with the outside air, and foul air is extracted through the upper half, which opens into the chimney."

Outlets should be of about the same size as inlets, or rather larger, and they should be placed a considerable way from inlets, and as a rule high up.

Perflation and aspiration, like thermal circulation, may be assisted. Perflation may be assisted by means of tubes between the outer air and the room, with a cowl-piece turned towards the wind. The stoke-holes and other confined spaces of steamers are ventilated on this principle, and in Egypt air is often brought in through the tops of houses by similar means. On this principle, too, is based what is known as Sylvester's method of ventilation. In this system of ventilation wind is led by a cowl and funnel to an underground channel, and thence, after being heated, it is led again by outlet tubes into the outer air.

Aspiration may possibly be assisted by some forms of cowls; but their value is doubtful, and a sub-committee appointed at Leamington in 1878 to investigate the ventilating capacity of exhaust cowls reported: "After comparing the cowls very carefully with each other and all of them with a plain open pipe, as the simplest and, in fact, the only available standard, the sub-committee find that none of the exhaust cowls cause a more rapid current of air than prevails in an open pipe under similar conditions, but without any cowl fitted on it."

Artificial Ventilation.

In the case of large rooms and buildings where many persons congregate, the natural processes of ventilation which we have described require to be assisted by artificial contrivances. The artificial contrivances are usually blowers or fans driven by steam or electricity, and they are designed either to force air into a building or to suck it out. If the method of ventilation be a forcing of air into a building, the system of ventilation is known as the "plenum" system; if it be a suction of air from a building, it is known as the "vacuum" system.

We will now look briefly at some of the methods of artificial ventilation.

(*a*) *Vacuum Ventilation.* (1) Extraction by Heat.—The principle of extraction by heat is the same principle as we have seen at work in ordinary ventilation by fire and flue or by gas and tube. In depends on the ascension and ejection of columns of heated air. Mines are often ventilated in this way. A fire is lit at the bottom of a shaft (the "upcast" or "return" shaft), and as the air in this shaft ascends air is drawn down another (the "downcast" or "intake" shaft) and through the galleries of the mine. "The current passes through the upcast shaft at the rate of from 8 to 10 feet per second; it flows through the main galleries at the rate of from 4 to 6 feet per second, or even more, and from 1,000 to 2,000 cubic feet per head per hour are supplied in good mines. In fire-damp mines much more than this is given, even as much as 6,000 cubic feet per man per hour."

In the case of large buildings there is usually a central shaft with a fire at the bottom, and into this shaft run tubes from the various rooms. Several French and English hospitals are ventilated in this way, and the ventilation of the Houses of Parliament and of some men-of-war is largely on the same principle.

The column of air in an extraction shaft may be heated by hot-water pipes (as in the Hôpital Lariboisière in Paris) or by steam or by gas. "It is calculated that each cubic foot of gas burnt is capable of extracting 3,000 cubic feet of air; thus twenty burners, each consuming 5 feet of gas hourly, will withdraw 300,000 cubic feet of air, corresponding to the complete renewal six times in the hour of the air of a hall 110 feet × 25 feet × 20 feet."

William H. Maxwell, in his treatise on "Ventilating, Heating, and Lighting," gives the disadvantages of ventilation by heat as follows:—

"(*a*) Inequality of up-draught as a result of the unavoidable variation in temperature of the furnace.

"(*b*) Owing to increase of friction in long air flues from distant rooms, there is considerable inequality of current, and the sectional area of the air-passages requires to be accurately proportioned to the resistance.

"(*c*) There is very little control over the source from which the fresh air is derived; it may be drawn from defective drains, water-closets, &c.

"(*d*) There may be a down-draught in the shaft of vitiated air or smoke into the room. Such has 'occasionally' been experienced in connection with the main vitiated air shafts ventilating the Houses of Parliament."

(2) Extraction by Steam-jet.—A jet of steam passed into

an extraction shaft will set in motion and drive before it a volume of air equal to 217 times its own bulk.

(3) Extraction by Water-spray.—Water-spray may be likewise used to propel and extract air. "A Kite's patent simplex water-jet air-propeller will extract 1,000 cubic feet of air for each gallon of water." Pettenkofer's Laboratory of Hygiene in Munich is ventilated on this principle.

(4) Extraction by means of Fans.—Various fans, such as Guibal's Fan, or Root's Blower, or the Sturtevant Blower, or the Blackman Air-propeller, are used. The fans are constructed like the screw of a steamer, and are set in a circular opening through which the air is aspirated as they revolve. Fans are particularly useful when it is desirable to remove air containing dust or germs or poisonous vapours. Thus they are much used in cotton, woollen, silk, worsted, and flax factories, and in dry, grinding processes of the metal trades. The dust of wool is liable to contain anthrax spores, and so it is especially desirable to suck the dust away from the workmen, and "in the wool-sorting trade, each bench on which the wool is sorted has an opening leading, by means of a pipe, into the extraction shaft, at the extremity of which the exhaust fan is working."

(*b*) "*Plenum*" *Ventilation.*—Practically all "plenum" ventilation is effected by means of fans; and Blackman's fan, which is capable of supplying from 6,000 to 12,000 cubic feet of air per hour per horse-power, is much used for this purpose.

The comparative advantages of "vacuum" and "plenum" ventilation have been much discussed.

When "vacuum" ventilation is used, it is difficult to control the source of the air and ensure purity. When, on the other hand, the "plenum" system is used, the air driven through the inlet can be derived from any source, can be impelled at any rate, and can be carried by tubes for a long way if necessary; it can also be heated, and filtered, and moistened, or dried, as desired. In these respects the advantage is certainly with the "plenum"; but some authorities think that air driven through shafts loses some subtle vitalising quality. Parkes and Kenwood assert that "air which has travelled through lengthy shafts and special air chambers has lost its freshness, and is liable to cause lassitude and a feeling of depression amongst those who habitually come under its influence. Chemical and bacterioscopic examination may demonstrate the purity of such air, but none the less there is reason to believe that in such air the vitalising principle characteristic of really fresh air is diminished. The essential distinction between town and country air is likewise probably due to a diminution or deterioration of the unknown vitalising principle present in a purely natural atmosphere. The very artificiality of the plenum system, which permits of the air supply being regulated with great nicety as to volume, temperature, moisture, &c., robs it at the same time of the refreshing qualities so important for the maintenance of a good standard of health." Mr. J. Keith, too, in his report on the ventilation of the Houses of Parliament, states: "I think *extraction* rightly applied is infinitely better than *propulsion*. I never knew of a system of propulsion pure and simple that effected an efficient and satisfactory ventilation of any large building. In the case of the House of Commons there is no lack of *fresh* air sent in, or that can be sent in; the trouble is rather to get rid of *all* the vitiated air—and that can be done effectively by a proper system of extraction, by which the vitiated atmosphere could be drawn on at various points." Douglas Galton also writes: "In practice the system of propulsion, *i.e.*, forcing the fresh air into the room, and allowing the vitiated air to find its way out, has not been generally found successful as a means of purifying the air. The air forced in seems to seek the first place of escape, and unless the system is combined with an efficient system of extraction, *much of the vitiated air may remain in corners and dead angles.* It is therefore generally advisable to combine with a system of propulsion for the inflowing air some method of extraction for vitiated air."

In most cases nowadays a combination of plenum and vacuum ventilation is used. In the Capitol in Washington, in the London Law Courts, in the Houses of Parliament, and in many other buildings there are both extraction and propulsion. The ventilation of the Houses of Parliament is thus described by Mr. J. Keith in his report of March, 1894:—

"The extraction of the vitiated air is solely obtained by the adaptation of the main towers as aspirating shafts, at the base of which coke fires are kept burning continuously throughout the year. Into these main upcast extract shafts the vitiated air is drawn considerable distances—upwards, downwards, and horizontally—from the ceilings or upper parts of the rooms, corridors, &c.

"In summer the incoming air is washed and cooled in the lower floors before being admitted into the chambers, rooms, and corridors. In winter the fresh air is warmed by steam-pipes and steam-heated surfaces before being passed on to the different sections.

"The Debating Chamber of the House of Commons is, however, differently treated; and though the extraction of the vitiated air is secured in a similar manner by means of the upcast shafts in the towers, the system otherwise is entirely separate and different in principle from the rest of the buildings. The ventilation of the Debating Chamber of the House of Commons is, in fact, obtained by a combination of what is called the plenum and the exhaust or extract systems of ventilation, the fresh incoming air being blown in in volume under pressure by a powerful fan or propeller placed in the basement, the vitiated air being extracted from the ceiling, and then drawn downwards and onward by aspiration into the base of the heated upcast shafts mentioned. The action of the aspirating upcast shafts being much less effectual in exhausting, even in winter, than the action of the plenum fan is in blowing in the fresh air upwards through the grated floor of the chamber, there is always, as it were, a slight pressure of air from the interior of the Debating Chamber and division lobbies outwards, and this is sufficient to prevent any egress of air from the lobbies and corridors into the House of Commons proper. The incoming fresh air for the House of Commons is also washed and cooled in summer before being sent in under pressure, while in winter the air is warmed by steam-heated surfaces after being taken up and blown in by the propeller.

"In foggy weather the cooled or warmed air, as the case may be, is sent into a large, peculiar, and ingeniously constructed **V**-shaped screen arrangement, having a surface of about 1,000 square feet of cotton-wool fixed to it, and through this the air is filtered on its passage between the propeller and the Debating Chamber."

In the Victoria Infirmary, Glasgow, a method of ventilation known as Key's method is used. It is thus described by Maxwell:—

"The cold fresh air is drawn through an air-cleansing arrangement by Blackman fans, placed between the cleansing and warming chambers and the air flues to the wards.

"The fans draw in the fresh air from the outside down a large inlet, lined with white-glazed bricks. It is then admitted to a chamber divided by a close hanging screen, which is fixed to a beam near the ceiling, and connected with a longitudinal trough filled with water. The screen is of cocoanut fibre stretched from a beam at the ceiling to one near the floor, and is kept moist by water drawn from the trough by means of capillary attraction through a loose piece of flannel hanging over its edge. Dust, soot, &c., from the air, as it filters through at a low velocity, is thus retained on the wet screen and carried down two or three times an hour, to float away by flushes of water from an automatic flushing tank. After leaving the screen the air is warmed, if necessary, by contact with steam-heated surfaces. The air is then collected by a Blackman air propeller, worked by electric motors driven with power from the laundry engine, and passed in air ducts leading to the various rooms and buildings.

"This system is said to remove every particle of fog from the air, so that even under conditions of dense fog outside the air in the wards is kept clear and bright."

The question of the *direction* of ventilating currents of air has been much discussed. A *down* draught has been recommended by some authorities on chiefly the grounds that impurities in the air collect near the floor and that it is easier to avoid the entrance of dust and draughts if the air passes out through the floor than when it passes in through it. The subject was fully considered by experts in connection with the ventilation of the House of Representatives, and the following opinion was expressed :—

"The relative merits of the upward *versus* the downward systems of ventilation in large halls in which the centre of the room is occupied by a number of people may be estimated from the following considerations :—

"First, the direction of the currents of air from the human body is, under ordinary circumstances, upward, owing to the heat of the body. The velocity of these currents is small, but it may be estimated as being certainly not less than 1 inch per second. This current is an assistance to upward and an obstacle to downward ventilation.

"Second, the heat from all gas flames used for lighting tends to assist upward ventilation, but elaborate arrangements must be made to prevent contamination of the air by the lights if the downward method be adopted.

"Third, in large rooms an enormous quantity of air must be introduced in the downward method if the occupants are to breathe pure and fresh air. The whole body of air in the room must be made to move uniformly downward, for if at any point this be not the case, the products of respiration will rise at those points, and, diffusing, contaminate the air which is coming down to be breathed. The uniform rate of descent should certainly be not less than 3 inches per second, in order to overcome the ascensional tendency of the currents from respiration, the heat of the body, &c., which implies that for every 100 square feet of floor area at least 1,500 cubic feet of fresh air are to be brought in per minute. As the floor of the hall and galleries of the House contain 12,927 square feet, it follows that the amount of fresh air required would be 193,500 cubic feet per minute, or about three times the amount which is found to give satisfactory results with the upward method.

"Fourth, in halls arranged with galleries the difficulty of so arranging downward currents that, on the one hand, the air rendered impure in the galleries shall not contaminate that which is descending to supply the main floor below, and, on the other hand, the supply for the floor shall not be drawn aside to the galleries, is so great that it is almost an impossibility to effect it.

"For these and other reasons the Board are of opinion that the upward method should be preferred. In the upward method there are two special difficulties to be met in halls of this kind. The first is dust derived mainly from the shoes of the occupants. This, becoming dry, is ground into fine powder, some of which is kept floating in the air by the upward currents. By careful supervision, and by the use of carpets which can be easily detached and frequently shaken, as is done in the English House of Parliament, this evil can be so mitigated as not to be noticed.

"The second difficulty is due to the discomfort produced by perceptible currents of air. The cause of this is insufficient area and improper position of the openings for the admission of fresh air. If the area of openings be too small, the air must pass through them with too great velocity in order to obtain the required quantity. In a hall liable to be so fully occupied as this, there are few points at which fresh-air openings can be placed the current from which will not impinge on some part of the body of some occupant, and if it does so impinge the velocity should not exceed 2 feet per second in order to avoid sensations of draught. The supply of air for the House should be, as we have seen, from 600 to 1,200 cubic feet per second, whence it follows that the total area of openings should be nearly 500 square feet. It is desirable to diminish the effect of these openings as much as possible by placing at least a part of them at points where the currents will not reach a person for several feet, or until they have become somewhat diffused. In attempting to effect this it is very important to remember the law of the adhesion of gases to surfaces, and it is from omission to do this that a large part of the discomfort of members of the House has arisen. It should be distinctly understood that the Board states these general principles only as applicable to large assembly halls where a number of people are gathered in the centre of the room, for under other circumstances some of them do not hold good."

The question of the heat and moisture of indoor air comes naturally into the question of ventilation.

There are five main methods of heating: (1) Open fires.

(2) Gas fires. (3) Stoves. (4) Hot air. (5) Hot-water and steam pipes.

(1) Open fires, as we have seen, are most effective vacuum ventilators.

(2) Gas fires are much less effective than open fires in promoting ventilation, and if their flues are too small they render the air dry and oppressive and may also allow carbon monoxide to escape.

(3) Stoves are also less effective than open fires in promoting ventilation. They also render the air dry and hot unless vessels of water be placed on them, and they also—especially if made of cast iron—give off carbon monoxide. Stoves can be approved only if they (*a*) are provided with proper chimneys; (*b*) are of such a pattern that they cannot become red-hot or otherwise contaminate the air; and (*c*) are supplied with fresh air directly from the outside.

Red-hot iron, especially cast iron, is believed to allow carbon monoxide to pass through it. It also chars organic dust particles and produces an unpleasant smell.

(4) Hot air.—In systems of ventilation the air is frequently heated at the inlet opening. It may be heated in various ways—by being passed through boxes containing coils of hot-water pipes, by being warmed in a tube passing through a stove, or in a jacket surrounding a stove, by being passed through ducts warmed by the heat of an ordinary fireplace, &c.

Manchester stoves are much used in schools and hospitals. In these stoves the cold air supply is brought along between the joists of the flooring, is led through a chamber at the back of grate into tubes which pass round the hottest part of the flue, and then is discharged into the room through a grated opening at the top of the stove.

Furnaces.—In the case of hot-air furnaces the cold air is led into "a chamber in the upper part of the furnace above and surrounding the 'dome,' where it comes in contact with the very hot surface and is heated by convection. Thence it passes upwards through separate tin tubes to the several places for its discharge." A hot-air furnace of this kind is a most efficient ventilator, for it passes a constant current of warmed air into the rooms. "Where and how it all escapes is a matter of secondary interest and importance, for it gets out wherever it may find its way."

(5) Hot-water pipes and steam pipes.—On this system of heating hot water or steam is led in pipes through the building and circulates by means of convection currents set up by its own heat. The hot-water system may be either high pressure or low pressure. This is quite a healthy mode of heating rooms, but is not so favourable for ventilation as open fireplaces, and there is a tendency to overheat the rooms.

The influence of sunlight in heating rooms must not be forgotten, and it may be noted that the outside air on the south side of a house is always several degrees warmer than on the north side.

At what temperature ought indoor air to be maintained? This is a moot question. In England about 60° F. is considered the best temperature; while in America, where the air is drier, a temperature of about 70° F. is considered desirable.

In a general way it may be said that the lower temperature (60° F.) is probably the more favourable for health and activity.

The question of moisture in the air is also closely related to the question of ventilation. As a rule, ill-ventilated air becomes saturated with moisture, and the evil effects of ill-ventilation are due in a large part to this saturation. Damp walls, too, by preventing evaporation of moisture, increase the dampness, and to this action their evil effects are chiefly due. The airing of rooms not only purifies the air, but also to some extent dries it.

In air, however naturally very dry or unnaturally heated by artificial means, there may be a saturation deficit so great as to be detrimental to the health. At Fort Yuma, in Arizona, the mean relative humidity is only 35 per cent., and newspapers crack when handled and furniture falls to pieces, and the skin becomes dry and hard. At some of the high Alpine stations the dry cold air when heated acquires such a large saturation deficit that the mucous membranes of the nose and throat become dry and cracked. All air when heated acquires greater capacity for water and greater drying power. Thus "air at 25° F. saturated with moisture would need more than ·5 pint of water in every cubic 1,000 cubic feet to give it a humidity of 65 per cent."

It is usually held that at a temperature of 60° F. to 70° F. a relative humidity of 65 to 75 per cent. is healthiest, and if the humidity of air in rooms falls much below this it is well to take means to supply moisture to the air. Moisture may be supplied by means of pans and porous vessels of water, or by means of cotton wicking kept moist, or by means of steam. The air in the building of the American Bell Telephone Company, in Boston, is kept at a humidity of about 50 per cent. by steam, and to maintain this humidity no less than 675 gallons in the form of steam are required in ten hours. "Certain parts of the building which, before the adoption of this process, had been heated with some difficulty, are now made more comfortable, and in the whole building 3 degrees less heat are required for the maintenance of an agreeable temperature. According to Mr. C. J. H. Woodbury, under whose direction the plant was installed, another feature indicating the greater comfort of the building was the absence in winter of the coughing by those employed there, a cough of the bronchial kind or from the lungs, a cough which ends with a squeal, which is so prevalent in New England during the winter, especially in those employed in offices."

Filtration of Air.—Where the air is filled with dust and particulate impurity it may be desirable to filter it; and this is sometimes done. The air, for instance, entering the building of the American Bell Telephone Company, in Boston, is filtered through large cotton bags 30 feet in length, and about a peck of organic and inorganic dirt is caught every month.

Efficiency of Ventilation.—The efficiency of ventilation can be estimated in various ways. One of the best methods is intentionally to vitiate the air of a room, and then after the lapse of a certain time find how far ventilation has removed the carbon dioxide. The amount of air which has entered may be found by the following formula :—

$$C = 2{\cdot}303\, m \log \frac{P1 - a}{P2 - a}$$

C = amount of air which has entered.
2·303 is a constant.
m = capacity of the room.
P1 = amount of carbon dioxide originally present (found by experiment).
P2 = amount of carbon dioxide present in second sample.
a = amount of carbon dioxide in the external air.

The most important practical points of ventilation are thus summarised by Parkes and Kenwood :—

"1. When air is heated it expands and tends to rise; when air is cool it contracts and tends to fall.

"2. Cold air tends to enter a room and to move about very much as water would; and this holds true so long as the temperature of the fresh air remains lower than that in the room.

"3. The extent of inlet provision for fresh air is not quite of the same importance as that for the exit of foul air; for if foul air is extracted in sufficient quantities, fresh air will enter somehow to replace it, as by skirtings, crevices in doors and windows, or even through the brickwork of the walls.

"4. The inlet provision for fresh air should average 24 square inches for each individual; the provision of inlet areas somewhat larger than those of exit tends to minimise draughts.

"5. Inlets should generally be as low in the room as possible, viz., just above the floor (so as not to raise the dust) if the outside air is warm or has been warmed prior to entry, but at a height of about 5 feet if the outside air is cold; otherwise unpleasant draughts are experienced. As a further protection against unpleasant draughts when cold air is admitted, the incoming air should be directed upwards; while hot air, since it tends to rise, should be directed downwards.

"6. Outlets should in every case be as high as possible, and preferably close to or in the ceiling; and they should have their extractive powers maintained by means of heat or an exhaust fan, or they are liable to act as inlets.

"7. Where practicable, an effort should be made to so place outlets that the vitiated air is drawn towards them before mixing with the general air of the apartment.

"8. There is a tendency for fresh air to take a direct course to the outlets, and this must be counterbalanced by a judicious selection of the relative positions of inlets and outlets.

"9. Methods of ventilation devised to ventilate crowded premises are generally inefficient, unless the incoming air can be warmed in winter to about 60° F.; for then efficient ventilation by cold air cannot be tolerated, and there is a great tendency among workers to close all ventilating inlets.

"10. With less than 250 cubic feet per head, no ventilation can be satisfactory which is not aided by mechanical force.

"11. The source of the incoming air should be considered. It should not be borrowed from adjoining rooms, but taken direct from the outside. One great advantage of the more expensive mechanical system of "plenum" ventilation is the fact that sufficient air can always be obtained from a source which is known and selected.

"12. Ventilation dependent on the extraction of foul air is often more convenient than that in which propulsion is mainly relied upon; but the purity of the air is not so easily provided for or guaranteed.

"13. If warm air is forced into a room, it should only be raised to a temperature sufficient to prevent a feeling of cold (about 60° F.). More highly heated air is often felt to be overdry and unpleasant.

"14. The heating of the room should be effected by fires, stoves, or pipes in the room itself, and should not be made to depend upon the warmth of the incoming air.

"15. It is difficult and expensive to apply methods of mechanical ventilation to old premises."

Ventilation in General.—However ventilation may be carried out, any improvement in ventilation is always followed by improvement in health. This has been demonstrated in a most striking way by many statistics. Into such statistics we have not here space to enter; but a few naval figures may be cited by way of illustration.

In 1779, out of 70,000 men voted for service in the Navy, 25,592 were on the sick list, and 1,658 died.

In 1813, out of 140,000 men voted for service in the Navy, 13,000 were on the sick list, and 977 died.

In 1797,	out of	120,000	marines and seamen	20,544	were on the	sick list.
„ 1798,	„	„	„	15,713	„	„
„ 1799,	„	„	„	14,608	„	„
„ 1805,	„	„	„	8,083	„	„
„ 1806,	„	„	„	7,662	„	„
„ 1782,	„	100,000	„	22,909	„	„
„ 1795,	„	„	„	20,579	„	„
„ 1804,	„	„	„	7,650	„	„

This extraordinary fall in the sick rate was due chiefly, if not entirely, to improved ventilation.

CHAPTER XIII

OPEN WINDOWS, DRAUGHTS AND "COLDS"

VITAL thing though ventilation be, it is seldom or never satisfactorily practised. Both natural and artificial ventilation are hampered by fears of draughts; and anxious experiments are made to discover exactly how many feet air may be permitted to move per second and how much cubic space is necessary to allow change of air without draught. Fear of perflation, which is the best form of ventilation, renders perfect ventilation quite impossible, and makes the state of the air in many private houses and public places a disgrace to civilisation. Look at this picture. "Take, for instance, the case of a room, say about 12 feet 6 inches square and 9 feet in height, in an ordinary terrace house, as tenanted by the artisan and labouring classes. Here we have a cubic capacity, allowing for deductions for furniture, large projections, as chimney breasts, &c., and space occupied by the bodies of persons, about sufficient—according to the standard laid down by Dr. Parkes—for one adult, provided the ventilation is perfect and the air of the room changed three times per hour. But what are the actual conditions prevailing in numbers of such rooms? Doors, windows, and blinds, all closed or drawn, and no provision whatever for ventilation; often there may be five or six occupants in the room, which, as we have already seen, is only sufficient for one adult, even with perfect ventilation; the air strikes one on entering as being manifestly impure and much too hot for health or comfort; it is oversaturated with moisture, highly charged with organic matter from the breaths and bodies of the occupants, and the carbonic acid derived from the breath and combustion of lights is found to be much in excess of the prescribed limit of permissible impurity. To these may oftentimes be added the stale smell left by previous tobacco-smokers, and similar fumes also being given off by one or two of the present occupants. In addition to all this, in not a few cases are we likely to find the whole atmosphere of the house pervaded with some such smell as that derived from the cooking of kippers, or some equally odoriferous dainty!"

That is by no means an exaggerated description. Or take the atmosphere of an ordinary bedroom, of a railway carriage, of a church, or of a theatre. In nine cases out of ten the air is offensive and foul. In a railway car running between St. Petersburg and Moscow the carbon dioxide was found after nine hours to amount to 94 in 10,000—about 8 times the permissible maximum—and in a workshop, as we have seen, Haldane and Osborne found 57 in 10,000. Not only is such vitiation common, but it is often complicated and aggravated by fusty smells from old wall-papers and by evil smells from malodorous courtyards.

Now, if we are to accept the verdict of sanitarians such defective ventilation is in most cases quite inevitable.

Notter and Firth point out that even with the best mechanical contrivances, and with disregard of cost, no air-space of much less than 600 cubic feet can be well ventilated without perceptible movement; and that if mechanical contrivances are wanting or inferior, adequate ventilation means intolerable draughts—"in barracks with 600 cubic feet per head, the rooms are cold and draughty when anything approaching to 3,000 cubic feet per head per hour are passing through, that is a change of five times per hour for each 600 cubic feet of air-space. A change equal to three times per hour is all that can be borne under the conditions of warming in this country, or that is practically attainable with natural ventilation, and if this be correct, from 1,000 to 1,200 cubic feet should be the minimum allowance for the initial air-space."

Dr. Whitelegge confirms this estimate and says: "It is found experimentally that with ordinary appliances and under the average atmospheric conditions of the climate of England, the air of a room cannot be changed more than about three times an hour without causing inconvenient draughts."

Again, Harrington warns us that "draughts which are productive of discomfort are more dangerous than the ordinary vitiation of the air, and, therefore, complete ventilation with draughts is worse than partial ventilation without draughts"; and Parkes and Kenwood assert that "with less than 250 cubic feet of space per head no ventilation can be satisfactory which is not aided by mechanical force."

If these statements are correct, how can we expect to ventilate such a room as that described by Maxwell? Suppose there are only two gas-jets; yet even so there are less than 100 cubic feet per head, and in order to keep the air reasonably pure it would have to be changed 10 to 30 times an hour. How are we to change it 10 to 30 times without causing a draught? How are we to ventilate a railway carriage where each occupant may have only about 30 cubic feet of air-space? How are we even to ventilate a school with 200 cubic feet per head, or a crowded assembly-room with about 150 cubic feet per head?

If draughts are dangerous, then even with the most perfect artificial contrivances adequate ventilation is impracticable, and we must consent to partial ventilation such as Maxwell describes, and must agree with Billings when he says: "We may write and talk as much as we please about the horrors of bad air and the importance of good ventilation, but we shall never induce people to sit in cold draughts and shiver for the sake of pure air, and in fact we would not do it ourselves."

All the writers on ventilation assume that ventilation which causes any perceptible motion of cool air is not permissible. But why? Simply because the unnatural habits of so-called civilised peoples render them unduly sensitive to draughts; and because, through erroneous reasoning, cold air and draughts are considered dangerous.

The most satisfactory of all forms of ventilation is just that form most feared and avoided—perflation by means of open windows. In the open air we have no meagre 3,000 cubic feet of fresh air per head per hour; but no less than 30,000; and if we ventilate a room by means of door and window it is possible to renew the air in the room more than a hundred times even on a calm day. Parkes and Kenwood admit that such a method is of unquestionable utility for rapidly changing the air of an occupied room, and many people open their windows when they leave a room and shut them when they return.

Now, this prejudice against open windows and moving air seems on the face of it most absurd; for the very people who fear to open the window because of the perflation it permits, will walk boldly through the open door even into gales of wind. It seems absurd; yet the prejudice is so general that it must have some plausible basis.

Why do nine people out of ten nurse this prejudice?—why do some people hang curtains before their doors and put sandbags around their window-chinks and do all they can to ensure a hermetically sealed apartment and thoroughly foul air? It is not merely a question of comfort but also a matter of health, for these ill-guided people agree with Harrington that "draughts which are productive of discomfort are more dangerous than ordinarily vitiated air." There is no belief more general than that "chills" (whatever these may be) and colds are caught by exposure to cold air and to draughts. "Aria di finestra colpo di balestra" (The air of a window is like a shot from a cross-bow) says an Italian proverb. The erroneous roots of this erroneous belief are not difficult to discover.

In the malarial days the man who went out after sundown was liable to be bitten by a malaria mosquito and to get fever, and the fever or *chill* was attributed quite naturally not to the mosquito but to the chilly air. Even still the idea lingers on the Riviera that one out after sundown will catch a chill.

Again, a man goes to a ball, and breathes air vitiated by hundreds of lungs pouring out excess of carbon dioxide, and by hundreds of perspiring skins giving off various emanations. And the air is not only chemically foul, it is also probably laden with germs thrown into the air by dancing feet and flying robes. In this hot, moist, foul, germy air the man is foolish enough to remain for hours. Then he goes home and finds next day that he has got a cold; and he does not blame the moist, hot, foul air of the ballroom, but says that he has got a "chill" (whatever that is) when he went out into the fresh air.

Yet again, a man goes a long railway journey, say, from Calais to Chur. He is shut with seven others into a compartment with an air-space of about 240 cubic feet. He carefully closes all the windows and ventilators to avoid a draught, and for twelve hours or so he and his companions breathe the same air over and over again. Before he reaches his destination the air is foul with organic emanations, laden with carbon dioxide and moisture. As a result his tissues are weakened and poisoned, and succumb to the first germs of "cold" that happen to alight on his respiratory tract; but he attributes the cold not to foul air but to draughts. It may be mentioned that in a crowded railway carriage 3,120 microbes were counted to fall on each square foot per minute.

It is always easy to make a scapegoat of a draught, and the worse the ventilation the more certainly will a draught be discoverable. Even in a railway carriage, with every window and ventilator shut, there will be draughts pouring down the cold window-panes, and the heat of the carriage will compel thin streams of cold air to pour in through the crevices.

Is there no sound foundation at all, then, for the almost universal fear of draughts and chills? Are draughts never dangerous?

Yes, there is a certain amount of danger in the *small* draughts which are the result of precautions against fresh air. The danger is twofold. *In the first place*, the inmates of a badly ventilated room are living in a moist, hot atmosphere, and therefore all their skins are probably moist and warm with dilated blood-vessels. Now, when a small draught impinges upon a small fraction of such skin it naturally (like any stream of cold air injected into warmer air) abstracts from that part of the skin a large amount of heat. Under natural conditions wind blows all over the body, and the vascular system meets cold air by reducing the supply of blood to the skin and by producing more heat. But what is the nervous system to do when it receives contradictory messages from the skin—when the skin as a whole says that the air is moist and hot, and when the skin on which the draught is blowing says that the air is cold. Naturally and inevitably the needs of the small area whereon the draught is blowing are ignored, and heat continues to be abstracted from it, with the result sometimes that chemical changes causing rheumatism are produced. The body is not intended for such fractional heating and cooling, and the blood supply to the skin cannot be arranged to suit such unnatural requirements.

In the second place, small draughts are concentrated currents of air, and thus are especially likely to raise dust and germs ; and ill-ventilated rooms and buildings are also especially likely to contain pathogenic germs.

But are *big* draughts—regular breezes through a room—never dangerous? Even a big draught may be dangerous, but only under unnatural or unhygienic conditions. Again the danger is twofold. In the first place, the draught may blow upon a person accustomed only to still, warm air, and the nervous system unused to such emergencies may either fail to sent out prompt vaso-motor impulses to contract the blood-vessels of the skin, with consequent undue cooling of the blood, or may be startled into causing too energetic contraction, with consequent tendency to congestion of the internal organs. In the second place, the draught may raise dust and germs.

It will be seen, therefore, that the dangers of draughts, large and small, are due either to indoor dust or to unhealthy skin-coddling. *Per se* a breeze in a room is as healthy as a breeze at the seaside. Provided rooms be properly clean, provided the draught is as big as a small breeze, there can be no harm, only good, from open windows.

But the windows must be really *open*. Maxwell says: "In England bedroom windows can usually be kept open at the top for a few inches all the year round." But windows open a few inches are just the open windows that cause unpleasant draughts. And why "*at the top*"? A window open at the top causes a much more unpleasant draught than a window open at the foot, and has no particular ventilative advantage.

The more widely the window is opened the less draught will there be, and the less risk of such physiological incongruity as we have mentioned.

The ordinary house, especially the ordinary house of the poor, will never be adequately ventilated until people learn to open their windows *widely*, and understand that fresh cold wind never gives any one "cold"; but, on the contrary, prevents "cold." It is not the engine-drivers and stokers of trains that catch "colds"—it is the passengers in the stuffy carriages.

Cold air no more causes cold than it causes scarlet fever; and all pulmonary troubles are less common where there is free ventilation. Consumption, influenza, bronchitis, common colds, are all more prevalent where there is insufficient perflation; and it has been noticed that peasantry moved from ramshackle huts into buildings with good walls and well-fitting doors and windows become a prey to chest diseases. In the case of animals the same thing is found—"old ramshackle stables full of cracks and crevices are healthier than brand-new buildings with tight doors and windows and impervious roofs." But perhaps the best proof of all is seen in the open-air sanatoria, where, in spite of open windows day and night, colds are almost unknown.

A "cold" is a germ disease, and though the germ of common cold is unknown, yet there is no doubt that it flourishes best in dark, ill-ventilated places. When a house is free from dust, when it is washed out daily with sunlight and air, its inmates will be almost free from "colds." When, on the other hand, it is dirty and dark, there will be a constant crop of "colds." A very interesting illustration of the germ origin of cold was afforded by an experience of Shackleton's Polar party during their recent expedition.

The party were quite free from colds till they had occasion to unpack a case of blankets. No sooner were the blankets unpacked than all the party contracted violent colds. No doubt the germs had been packed with the blankets and had been alive in the dark box. A similar epidemic of colds frequently occurs in the lonely land of St. Kilda when strangers visit it. The lonely wind-swept island seems free from the germs of colds, but as soon as they are imported by visitors, the inhabitants fall an easy prey.

In this connection it may be suggested that the "colds" in spring, which are so often attributed to the putting on of thin summer garments, are not due to the thinness of the garments but to the fact that they have been taken from dark boxes and wardrobes, and are therefore thronged with germs.

When houses are frequently visited by colds it often means that they are dirty and full of germs, and they should be cleaned, disinfected, and well ventilated. And if an open window does cause colds it can only be because it stirs the dust of ages in dark corners and crevices. The day will come when it will be considered as uncivilised to breathe air off dirty carpets and wall-papers as to eat food off dirty plates.

It seems never to be noticed that open windows let in not only air but also sun. It might be thought that even shut windows let in enough sunlight; but it may be pointed out that glass is opaque and impervious to certain rays of the sun, and that these rays may be of the greatest importance to health.

To sum up, then, widely open windows will never cause colds in clean houses; and in open windows lies the solution of many problems of ventilation and public health. Ventilation as at present practised is both costly and inadequate: open windows are both cheap and adequate.

Further—and this point has always been ignored—stagnant air, however pure, is unnatural air, and any ventilation that means still air is bad ventilation. The imperceptible ventilation which is the ideal of sanitarians is a delusion and a fraud. Health requires *perceptibly* moving currents of air. The skin is man's broadest surface of contact with the external world, and it is not made sensitive to heat, and cold, and touch without good reason. To protect the skin from wind and cold and variations in temperature is to institute a wholly unnatural environment. Wind to the skin, variations in heat and cold are natural stimuli of the constitution, and the natural man has a nervous system and a vascular system that react to these and require these. The man who protects his skin with too many shirts, or too many double windows, is living an unhealthy and unnatural life that will probably end in disaster. It is largely the sea breezes and the mountain breezes that make residence by the sea and in mountain districts so stimulating. Perflation is the essence of good ventilation.

But it may be said that a cold breeze in a room is martyrdom. For seven months in the year in the English climate open windows mean no martyrdom at all, and those who accustom themselves to them soon find themselves much more than repaid by increased health and vigour for any occasional discomfort. For five months in the year open windows in England do mean considerable discomfort; but habit and a little extra food and clothing will do much to render the cold tolerable. Even if the discomfort of open windows in the daytime be in winter more than most men would willingly endure, it is always possible to have eight or nine hours of open windows at night without any discomfort whatever. To a man in bed with a plentiful supply of blankets open windows are no affliction; and the writer has seen men and women lying comfortable and cosy in bed with snow on their counterpanes. If only men would practise full ventilation at night nature would forgive them a good deal of bad air by day; but it is chiefly by night that they insist on stuffy rooms. The smell of the ordinary bedroom in the morning is enough to turn one sick. The idea that night air is dangerous is only a superstition which we have already explained away. Night air is really purer in all respects than day air, and open windows—*wide* open windows—by night would increase the health and the vigour of the English nation by at least 10 per cent.

"We spend so much of our short life in bedrooms," writes MacCormac, "that with a pure bedroom atmosphere, pure and fresh, in fine, as is the outer atmosphere itself—for here nothing less will suffice—there would, as I affirm and maintain and, with all my convictions believe, be no tubercle and consequently no scrofula, no consumption whatever."

"The longe-woo cometh oft of yvel eire,
The stomach eke of eire is overtake;
Take heede eke yf the dwellers in that leire
Her wombes sydes reynes swell or ake—
If langoure in thaire bledders ough' awake.
And if thoue see the people sounde and faire,
No doubt is in thy water nor thin aire."[1]

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[1] Palladius, "On Husbondrie," early fifteenth century MS.

CHAPTER XIV

THE CHEST AND BREATHING

FROM all time, a large chest measurement has been popularly considered a sign of muscular and constitutional vigour; and a big chest measurement is the highest ambition of many athletic youths. Yet a big chest measurement is not always all it appears to be: it may be associated with deficient breathing capacity, and it may even in itself be a symptom of disease. We cannot lay down as a general law that a big chest is a good chest, and a small one a bad one, and to condemn a man for the Army because he has a small chest measurement is like condemning him because he has a small nose.

The chest is not a box, it is a bellows; and its respiratory capacity depends not on how much air it can hold, but on how much air it can change; and this does not necessarily depend upon its size. A man with emphysema may have a large chest, yet it is not much use to him since its bellows action is defective: Wolfe, the Channel swimmer, had, as we have seen, a 51-inch chest; but as soon as the nerve-centre, or the muscles moving it, became tired, it was no better, perhaps much worse, than a 30-inch chest. Dr. Harry Campbell found that the champion weight-lifter of the world, a man with an enormous chest, had very small "vital capacity"; while the biggest vital capacity he ever registered he found in a man of thirty (6 feet 4 inches in height) with a small chest of only 35 inches.

The real value of the chest as part of the machinery of respiration depends chiefly on its mobility and not on its size. As age increases the chest usually grows larger; but the breathing is not better, but worse, because the mobility of the chest is decreased. The most that can be said for a large chest is that it offers a larger aërating surface, and that any degree of movement means more than in a small chest. It may further be said that a large chest, if *naturally* large, is usually a presumption of vigour, for it is usually natural vigour that has made it large.

Still, as we have said, it is the mobility and not the size that is the criterion of efficiency. This criterion, too, must be applied with care, for it is possible to decrease and increase the size of the chest merely by contraction and relaxation of the chest muscles, or by alteration of the position of the shoulders, and indeed many large chests consist not of large lungs but of large chest and shoulder muscles which are usually merely a tax on the respiration.

One hears of chests with enormous power of expansion, 15 and even 20 inches; but except in a few pathological cases the expansion is due not to increase of the size of the thoracic cavity, but to swelling of contracted muscles and to alteration in their position. The big muscles behind the armpits can be easily arranged so as to require a few inches more or less of tape. Fifteen inches of expansion is hardly credible. After all, the ribs are made of bone, not of elastic, and the possible increase and decrease in the size of the thorax by their elevation and depression has certain definite limits. A chest expansion of 3 to 5 inches is probably capable of supplying all the oxygen the blood can possibly absorb.

The *shape* of the chest is a subject on which there are many misconceptions. One hears that So-and-so has a fine deep chest, and that So-and-so has a flat chest; but really, deep chests and flat chests are much more a matter of carriage than of actual anatomical difference. A deep chest may be made to seem quite flat by hunching the shoulders and bringing them somewhat forward; and again, a chest apparently flat may be made to appear deep, simply by holding the head up and the shoulders back, and much of the apparently improved physique due to drill and gymnastics is really fictitious and does not indicate anatomical development. Indeed, regarded anatomically, a flat chest is better developed than a deep one. Before birth the chest measures more from before back than from side to side; at birth the measurements are equal; while in robust adult life the measurement from side to side is 30 per cent. greater than from before back. In old age, again, the chest tends gradually to return to the round shape. Not only so, but it will be found that the chest of phthisical individuals is really deeper, not flatter, than the chest of a healthy man, and that its apparent flatness is due to the thinness of the chest wall, and to the falling forward of the shoulders.

We have said that the value of the chest as *part* of the machinery of respiration depends on its efficiency as a bellows; but of course the efficiency of the respiration *as a whole* is not determined by the efficiency of any one part; and though the bellows may be all right, the heart may be weak, or the blood poor, or the nerve force feeble, and so respiration as a whole may be defective. A man's functional efficiency is not to be judged either by the size of his chest or by its mobility, but rather by the amount of oxygen he habitually consumes, and the amount of muscular energy he can expend without respiratory failure; and though mobility of the chest may be necessary for a good record in these respects, yet other factors are necessary too.

It may be inquired how far gymnastic exercises which develop the chest increase the respiratory capacity. To a large extent, as we have said, the apparent development is merely muscular and postural, and to only a small extent do gymnastic exercises really enlarge the thoracic cavity. Still the increased muscle, the altered attitude, and the enlargement of the thoracic cavity in conjunction *may* mean increased respiratory capacity. The attitude and chest contour of a trained soldier is certainly very different from the attitude and chest contour of a raw recruit, and the question is, Does the difference imply greater thoracic mobility, greater thoracic capacity, and better lung ventilation? There seems no special reason why it should: the muscles on the chest and shoulders play a very subordinate part in the respiratory movements, and, as we have mentioned, Dr. Harry Campbell found very low vital capacity in the champion weight-lifter of the world. Indeed there seems some reason to fear that gymnastic and drill training are often positively deleterious, especially in the case of soldiers. The enlargement of the thoracic cavity is often nothing more than a fixation of the ribs and breast-bone in a position of advanced inspiration, and this fixation interferes with the free movement of the chest, especially with *expiratory* movement, and ultimately damages the elasticity of the lungs and the mobility of the chest wall.

Many exercises are better for the "wind" than gymnastics, and Dr. Cavanagh ("Care of the Body") points out that no athletic exercise is better for the "wind" than walking, and urges the importance of avoiding exercises that "clamp" the chest. "It is essential to observe," he writes, "that there is in walking no interference with the easiest and the fullest breathing, since no forcibly contracting muscles are holding the shoulder girdle or the ribs or the diaphragm in any one fixed position. If you are an indifferent cyclist and endeavour to aid your difficult progression by pulling on the handle-bar, thus forcing the upper part of your thorax, the impediment to easy breathing will be at once apparent. For the same reason it is not right when doing dumb-bell or similar forms of exercise to stand with the shoulders well back, as is so curiously and universally prescribed. Stand up well, by all means; but the muscles must be 'limber,' not set hard. This is easily proved by testing it.

"The proof that no persistent violent exertion during which shoulders, back, or thoracic muscles are strongly contracted for more than one or two complete inspirations is good for the organism, should be the test of value. By it weight-lifting, for example, is absolutely condemned. Consider the physiology of this. A work is entered upon which must absolutely clamp the chest; yet the inspirations attempted will be of the deepest. Air being compressed in an imperfectly expanding cavity with a proportionate influence on the contractions and expansions of an already labouring heart, while at the same time an excess of blood is being driven to that heart—the working of which is thus doubly impeded."

This is well said. Exercise of the chest muscles, even if leading to an increase in the size of the thorax, may be positively harmful.

The prominent, pouting chest of the soldier, then, may be an anatomical deception, and a physiological iniquity. Still, in the cases of ill-developed chests where the ribs have adopted the position of expiration, sufficient exercise to lift and separate the ribs and increase the capacity of the chest is of value even if the mobility of the chest wall be not improved. A chest with the ribs more or less fixed in the position of extreme expiration is even more useless than a chest more or less fixed in the position of extreme inspiration, since, of course, it offers less surface for gaseous interchange, and also more impediment to the flow of blood. To expand such a chest, therefore, is both to increase its ventilating power and to assist the circulation through it. It must always be remembered that the elasticity of the lungs, as we shall show later, is of assistance to the heart, and that violent efforts may overstretch the elastic tissue.

In this relation we must consider the question of breathing exercises. In breathing exercises some people have found a certain panacea, both mental and physical, and on almost no subject has more nonsense been written. In the *Daily Mail* of the date on which we write, for instance, somebody writes to recommend a cure for influenza in the "pranayam" method of breathing. "As soon," he writes, "as you are awake in the morning, let into the room a good supply of fresh air; but beware of a draught. Then lie flat on your back without a pillow under your head, with your hands and legs relaxed as much as possible. Keep your mouth shut. Take a long, deep, and very slow breath as gently as you can through the right nostril. Retain as much of the air as possible in your well-inflated chest for about fifteen or twenty seconds. Then let out the air gradually through the left nostril. Take the next breath in the same manner, but through the left nostril, and let it out very gently by the right nostril. Breathe like this about ten times every morning through the nostrils alternately before you leave your bed." This exercise is not quite as absurd as it seems; but of course it could have no effect either in preventing or in curing influenza.

In an American magazine, under the heading "How to Breathe," we are told that "in inspiration the three lower ribs should first expand, and the motion should spread upwards; while in expiration the three upper ribs should first contract and the motion should spread downwards." We are further told that "oxidation is life, and the more deeply and frequently we breathe the more oxidation takes place and the more we live." Even those who ought to know better seem to lose their heads when they write about breathing. In an article in an English magazine a well-known tennis player gives his views on the Art of Breathing, and very extraordinary some of his views are. He states that most people have the left nostril closed, "partly because of the habit of holding the handkerchief in the right hand in wiping the nose." He tells business men that between important interviews they "may sit down and let their arms hang limp, and let the wrinkles go out of their faces. Then they should take a deep breath through their nose. After this inhalation they should contract the abdomen, and then gently expand it, letting the breath out slowly, and meanwhile relaxing every muscle as much as possible. The head will slowly fall forward, and their spine will bend forward too. This is just one exercise out of many. I only mention it because it is short and refreshing, and because it also clears the head for calm thought and clear judgment." After this we are not surprised to learn that one of the exercises of the Indian sages is to aspirate water into their nostrils in order "to cool their heads," and that during breathing exercises the thoughts "may be concentrated either at the top of the brain—the Indians often concentrate them just above the brain where the halo of saints is often found—or in the chest not far from the heart."

Even a doctor may be quoted to illustrate the foolish writing on the subject of respiration. In an American magazine we find a doctor talking with admiration of the feats of expansionists. "Ranking," he writes, "with the sword swallower and the man with the iron jaw is the man who by practice has developed his lung capacity, and the strength and mobility of his chest walls until some of his feats excite the wonder and incredulity of every beholder. A favourite act is to buckle a strap around a fully expanded chest, and then after forcing the air out to slip a hard felt hat between the loosened strap and the chest wall. This trick requires only a flat chest and an expansion of not more than six inches, and many a man who looks at it in astonishment would readily duplicate it with a little practice." Again, "many men have worked out their own methods of increasing their breathing capacity, one by holding his breath every time he crossed the street, another by filling the chest and gently pummelling it with his closed fists, and a third by bursting straps of increasing strength buckled about his chest."

Not a word of warning or disapproval does this doctor utter. Now, if these experimentists are working in order to exhibit themselves at Barnum's alongside the Fat Lady and the Skeleton Man, good and well, but if they think that they are increasing their "breathing capacity" by such feats they ought to be told that they are sadly mistaken, and that more probably they are ruining the natural elasticity of the lung tissue, and the relationship between breathing and circulation on which health depends.

Such pseudo-science as we have quoted is certainly reprehensible, and there can be no doubt at all that faddists have made too much of the science and art of breathing. In the first place it is necessary to recognise that breathing is essentially an automatic act regulated in a wonderful way by a multitude of reflexes. We breathe about fifteen times a minute, nearly twenty-four thousand times in the day, and every breath is timed and modulated by the necessities of the organism. The doctor flicks the face and chest of the new-born babe and it gasps its first breath, and from that time forth the breathing is under the control of reflex action. A little too little carbon dioxide in the blood and the breathing stops, a little too much carbon dioxide in the blood and it is stimulated. A little fever and it quickens, a little snuff in the nose and we have a sneeze, a little mucus in the throat and we have a cough. The breathing is at the mercy and under the control of many circumstances over which we have no control: it is essentially automatic and reflex. That is a fact to be noted,—that it is essentially automatic and reflex. But still it is to some extent under the control of the will, and it is quite possible that we may improve and educate it even without practising "pranayam."

Again, the main object of breathing, *quā* breathing, as we have seen, is to permit the consumption of oxygen and the expiration of carbon dioxide. But as we have also seen, the amount of oxygen consumed and of carbon dioxide discharged depends not on how deeply and how often we breathe, but on the metabolism—on the building up and breaking down of the tissues of the body, and this again is partly a question of constitution and partly a question of muscular activity, and is carefully and constantly regulated by the reflexes of respiration. To stand at a window and fill the chest and to imagine that one is oxygenating one's tissues is, no doubt, a pleasant imagination, but it is a delusion all the same. Nor can "pranayam" for ten times in the morning have the least effect on the twenty-four hours' interchange of gases. We are told by the apostles of deep breathing that by practising voluntary deep breathing the involuntary breathing will also become deeper. It is *possible* that the involuntary breathing *may* become deeper; but if so it is simply, so far as oxygen and carbon dioxide are concerned, a waste of muscular energy. Similarly we find enthusiasts blowing out their chests, and perhaps succeeding in increasing the measurement of their chests. Again it is largely a waste of muscular energy: they probably do not succeed in enlarging the bony case at all, they merely succeed, like the gymnast, in fixing the ribs in a rather higher position, and thus decrease the mobility of the chest wall.

Is there nothing to be gained, then, by practising breathing exercises? Yes, there is, if the exercises be practised intelligently and to good purpose. By deep breathing in the absence of exercise we cannot increase the metabolism of the tissues; we cannot increase the consumption of oxygen and the discharge of carbon dioxide, but we *can* maintain and increase the mobility of the chest wall and the power of the respiratory muscles, so that when the tissues themselves do require extra oxygen the lungs may be in a position to obtain it. But if we are to breathe deeply for this good purpose we must not merely inflate our chests and proudly maintain inflation at the expense perhaps of the elasticity of the air-cells; we must breathe easily and freely, and must remember that for this purpose it is quite as important to empty the chest as to fill it. It is the movement of the chest we wish to increase—the movement down as well as the movement up, and though this increase is probably much best attained by running and walking, and other exercises which naturally and reflexly emphasise the movements of the chest wall, yet simple breathing exercises are also useful.

Deep breathing, then, intelligently practised may be of use in maintaining and increasing the muscular power and mobility of the chest so that if called upon by the tissues to supply extra oxygen the chest may have the muscular power and the mobility to do the extra work.

The power of the thoracic muscles which expand the chest may be very great. Hutchinson calculated that a man taking a deep inspiration must have exerted a muscular power capable of raising 450 lbs., and in another case he estimated the muscular power as 1,000 lbs.

In a few instances deep breathing may be useful as a means of adding extra oxygen to the blood before violent muscular exercise, such as sprint races. As a rule any—and the amount must be very small—oxygen added to the blood by deep breathing *apart from exercise* is not taken up by the tissues; the tissues get their oxygen from hand to mouth just as they require it. But if a racer indulge in deep breathing immediately before a sprint race the tissues which during the race require all the oxygen they can get will find the extra oxygen in the blood very handy—the handier in that *during* many sprint races the runner fixes his chest and does not breathe at all. "Forced breathing for some minutes," writes Professor Leonard Hill, "allows the athlete to run much further without taking a breath and with much less distress." But these are, of course, exceptional cases, and even in these cases the benefit received from the deep breathing is probably due more to the washing out of carbon dioxide from the alveolar air than to the provision of additional oxygen. It is just possible, however, that since the tissues must to some extent accommodate their requirements to the supply of oxygen,—it is *just possible* that even breathing exercises by increasing the mobility of the chest may encourage the tissues to more extravagance.

But deep breathing has other uses—it assists the circulation of the blood and lymph through the thorax, and the diaphragm in its ascent and descent massages and squeezes the liver and the abdominal organs.

The mechanical relationship between breathing and circulation is interesting and important. The lungs during inspiration are stretched like a piece of elastic, and by their elastic traction they cause a certain amount of suction on the heart and big blood-vessels which lie between them in the cavity of the chest. This suction helps to bring the blood through the large veins to the heart, and it also assists the expansion of the heart after its contraction. The deeper the inspiration the more suction do the lungs exert, and the more do they assist the heart and the circulation. We see thus that deep breathing assists the circulation of the blood, and since deep breathing is caused by exercise it assists the circulation of the blood most just when it requires assistance.

This suction action of the lungs is probably of great physiological importance, and we find that if anything diminishes the elasticity of the lungs, such as injudicious exercise, or the disease called *emphysema*, or old age, the organism tries to maintain the suction action by holding the chest wall in a position of deeper and deeper inspiration. Further, if the heart be weak, we find that the chest expands in order to assist it. Hence, as we said before, a big chest is not necessarily a good one, and is not infrequently a symptom of disease or old age. The enlarging chest of later years is probably, like the wrinkled skin, just a sign of diminishing elasticity. Dr. Harry Campbell, whose theory we have been expounding, writes: "Were my lungs at this moment suddenly to grow twenty years older, I am quite sure that my chest would forthwith expand to a notable degree, through extra action of the inspiratory muscles, ever on the watch (through their nerve-centres) to maintain pulmonary suction at its normal level. Hence the steady increase in thoracic girth which tends to take place after middle life or even before it, and the shortening of the neck, as every tailor and dressmaker can testify. Many a man proud of his 40-inch chest would be much better off with a 36-inch circumference. The moderately flat chest with an index of 70 capable of a wide range of movement is the ideal one. Deepness of chest is a sign of degeneration, and goes along with defective mobility."

Deep-breathing exercises, then, may have certain utility in aiding the heart and circulation as well as in preparing the lungs for emergencies.

During deep-breathing exercises the body should be held freely and easily, and the movements of natural breathing should be imitated as closely as possible. The breath should not be held, and expiration should be as complete as inspiration.

Nose-breathing.—It will be well, especially if there be any doubt about the purity of the air, to breathe through the nostrils. The very act of deep breathing, by drawing the air more strongly into the deeper parts of the lungs, increases liability to infection if the air contains germs, and the nostrils are for the very purpose of warming, moistening, and filtering the air, and they should always be used for the purpose for which Nature intended them. Their efficacy both as a moistening and warming apparatus is very great. Air 14° F. below freezing-point if breathed through the nose is warmed to 77° F. by the time it reaches the throat, and air at 65° F. is warmed to 88° F.; and the air is always saturated with water to one-third of its capacity on its way through the nose. Thus, when people talk about the cold air affecting their chests they forget that it is the function of their noses to warm the air, and that their noses are specially constructed with warm vascular surfaces for the purpose. And the filtering function of the nostrils is equally perfect. Not only are they made in such a way as to offer an extensive moist, sticky surface to the air; but the sticky fluid, the so-called "mucus," wherewith they are moistened, is fatal to bacteria, so that they are a regular death-trap for germs. Any one who lives in a smoky city has merely to blow his nose to see how the soot is caught in its cavities. Strauss found that whereas there were 20,000 bacteria in inspired air, in expired air there were only forty, and probably the majority of those retained were caught by the nose. Under ordinary conditions the nose contains more than thirty different kinds of bacteria, and some of these may be germs which would cause disease if they passed the nose. A French scientist when making experiments with the germs of consumption—the tubercle bacilli—plugged his nose with cotton-wool, and afterwards was able to give guinea-pigs consumption with the germs caught on the plugs. The same germs, however, caught on the mucous membranes of the nose would have been destroyed, for St. Clair Thomson Hewlett found that the great majority of nasal cavities were aseptic, even in cases where the air was so impure that about 14,000 organisms were inhaled hourly. It may be noted that the downward direction of the opening of the nostrils and their devious course backwards renders access of germs and dust to the lungs very difficult. It is well known that by giving a bottle a long, narrow, twisted neck with mouth turned downwards germs can be kept out of it almost as well as if the mouth be sealed.

Of course the nose, even the largest nose, has its limitations and cannot catch everything; but still, whether we are breathing or deep breathing, it is well always to filter, to moisten, and to warm the air with the nostrils. Seeing the importance of the nostrils, any narrowing of their passages should at once be seen to.

George Catlin, a famous traveller among the Indians, wrote an amusing little book called "Shut Your Mouth and Save Your Life." In this little book he writes: "Where I have seen a poor Indian woman in the wilderness lowering her infant from the breast, and pressing its lips together as it falls asleep in its cradle in the open air, and afterwards looked into the Indian multitude for the results of such a practice, I have said to myself 'Glorious education! such a mother deserves to be the nurse of emperors!' And when I have seen the careful, tender mothers in civilised life covering the faces of their infants sleeping in overheated rooms, with their little mouths open and gasping for breath, and afterwards looked into the multitude, I have been struck with the evident evil and lasting results of this incipient stage of education, and have been forcibly struck and shocked when I have looked into the Bills of Mortality, which I believe to be so frightfully swelled by the results of this habit thus contracted, and practised in contravention to Nature's design. There is no animal in nature excepting man that sleeps with its mouth open. . . ."

Of course, this is the writing of a faddist; but there can be no doubt that in most cases it is healthier and safer to breathe through the nose. We say in *most* cases, for there are instances where nasal passages may be too narrow to supply sufficient air; and there are other instances, *e.g.*, during violent exercise, when even normal nostrils cannot supply the extra air required.

It may be noted that even apart from the moistening, warming, and filtering functions of the nostrils, nose-breathing has a particular effect on the pressure of the gases in the chest. Even when the nostrils are normally patent it requires rather more muscular effort to inspire and expire through the nostrils than through the mouth. Accordingly inspiration through the nose causes rather more suction, with rarefaction of the air in the lungs, than does inspiration through the mouth; and expiration through the nose causes more compression of the air in the lungs than does expiration through the mouth; and this greater rarefaction and compression must somewhat facilitate the discharge of carbon dioxide and the diffusion of oxygen. If we inspire air, after the "pranayam" fashion, through one nostril and expire it through the other nostril we still further increase the suction and compression; and in so far the "pranayam" has some sense in it; but it is nonsense, nevertheless, to imagine that a few breaths drawn in this fashion can have any effect on the general health. It is possible to cause still more suction in the chest by closing mouth and nostrils after expiration and then making the muscular movements of inspiration. This is known as *Müller's experiment.* It is possible also to cause still more compression by closing mouth and nostrils after inspiration and then making the muscular movements of expiration. This is known as *Valsalva's experiment.* Both experiments have physiological interest but are of little practical value.

There are various breathing exercises prescribed by specialists. In his fascinating book on "Respiratory Exercises," Dr. Harry Campbell divides exercises into (*a*) Active breathing exercises; (*b*) Active breathing exercises conjoined with other exercises; (*c*) Passive breathing exercises; (*d*) Exercises for developing the abdominal muscles. We may quote here, by way of illustration, the *active breathing exercises* he recommends.

"1. Take the fullest possible thoracic inspiration, followed by an ordinary expiration.

"2. Expire to the utmost, bending the body somewhat forward, and then take an ordinary inspiration, resuming the vertical position.

"3. Take the fullest possible thoracic inspiration, and then expire to the utmost, bending the body forward.

"4. Take a deep lower thoracic inspiration, followed by a deep lower thoracic expiration.

"5. Stand with the legs well apart and take a deep abdominal inspiration, followed by a passive expiration, *i.e.*, one resulting from recoil merely.

"6. Stand with the legs well apart and take a deep abdominal inspiration, followed by a deep abdominal expiration. This latter is effected by retracting the belly by means of the transverse muscle-fibres of the anterior abdominal wall.

"7. Take a deep abdominal inspiration, then a lower thoracic inspiration, and, finally, complete the breath by a deep thoracic inspiration, lifting the clavicles to the utmost. Expire in the reverse order.

"8. Take a lower thoracic inspiration and follow this up by a deep abdominal inspiration; make a deep abdominal expiration and, finally, a deep thoracic expiration.

"9. Assume the sitting posture, fold the hands on the lap, flex the body as far forward as possible. Now take the deepest possible abdominal inspiration with closed mouth, and then gradually raise the body, lift the arms over the head, and take the fullest possible thoracic inspiration. After this, passively expire—*i.e.*, by recoil merely—with open mouth, allowing the arms to drop suddenly. Expiration should not proceed beyond the limit of ordinary expiration, and should not occupy more than one second, inspiration occupying not more than six."

In some diseases respiratory exercises are distinctly useful. In heart-disease, in asthma, in certain bronchitic conditions, in emphysema, in some forms of indigestion, constipation, neurasthenia, they are of physiological service. In most cases of phthisis, however, it is usually best not to exercise the lungs. Tuberculosis, if at all active, implies inflammation, and inflammation requires rest. Only in cases where the disease is almost completely arrested, should any form of breathing exercise be used or should even singing be permitted. It is true one hears of wonderful cures due to singing and breathing exercises, but they are usually not well authenticated. On the other hand, breathing exercises are of great value for those merely predisposed to phthisis, since the breathing exercises increase the blood-supply of the lung and thus improve its nutrition.

Position.—We cannot leave the subject of breathing without reference to the question of the effect of habitual postures on the breathing capacity. A few minutes' breathing exercises or a few minutes of athletic exercises calculated to develop the chest's action, can hardly be expected to be productive of much good if for the rest of the day the chest is hampered and handicapped by faulty postures. If a child be allowed to sit all day with its chin between its knees, or to sit with its chest pressed against a desk or table, it can hardly be expected that a few dumb-bell or breathing exercises will prevent thoracic deformity. Children should always be taught to carry themselves easily and straightly, and should be prevented from adopting stiff or cramped attitudes.

Singing and speaking are both natural forms of respiratory exercise, and both, owing to the resistance of the vocal cords, cause compression of the air in the lungs, and assist the diffusion of oxygen.

The effect of public speaking as a respiratory exercise beneficial to the heart was recognised by Sir William Broadbent, who wrote: "The breathlessness due to dilatation of the heart is often relieved by exercise of the voice. I have met with numerous instances in which a clergyman has climbed into the pulpit with the utmost difficulty, and has not only preached a sermon comfortably, but has been all the better for it." Singers, again, are notably free from pulmonary troubles, and, as a rule, enjoy robust health and have vigorous appetites. We cannot, however, recommend the abdominal method of singing taught by Mandl, "whose pupils were made to sing while lying down on mattresses, sometimes with weights, more or less heavy, placed on the sternal region: masters were even said to make a practice of seating themselves familiarly upon the chests of their pupils. In the schools were to be seen gallows with thongs and rings for binding the upper half of the body, orthopædic apparatus, rigid corsets, and a kind of pillory which enclosed the frame and fixed the ribs."

A baby's crying is also good respiratory exercise, and children should be encouraged to shout at their play. Playing wind instruments, such as the bagpipes, causes great increase in the pressure of the air in the lungs, and is apt, indeed, to distend the air-cells, and to damage the elasticity of the lungs.

The enlargement of the chest cavity on which ventilation of the lungs depends is due partly to movements of the ribs and partly to movements of the diaphragm, and the proportionate part played by ribs and diaphragm varies very much in different individuals. With a little practice it is possible to breathe chiefly with the upper ribs, or with the lower ribs, or with the diaphragm, or with lower ribs and diaphragm, or with all the ribs. Strong diaphragmatic breathing is specially useful as a form of abdominal massage. The diaphragm, it must be remembered, is a very strong muscle, and its pressure downward in inspiration is very great—so great that a man lying on his back can easily lift another man sitting on the upper part of his abdomen simply by taking a deep abdominal breath. Dr. Harry Campbell knew a man who could lift a grand piano!

As this powerful muscle, then, moves up and down, it squeezes the liver and the abdominal contents. But it does more. Each time that it contracts it increases the general pressure in the abdomen and aids in diminishing the pressure in the thorax, and thus helps to force on blood and lymph from the abdomen to the heart.

It will be noticed that women who wear corsets breathe almost entirely with their upper ribs, so that their bosoms rise and fall. This may be beautiful, but it is unphysiological and greatly diminishes the breathing capacity. Under ordinary conditions the bellows action of the chest is so much greater than is necessary that the movement of the chest can be greatly hampered without respiratory embarrassment; but if any extra demand be made for breath, then the immobility of the lower ribs will prove a great disadvantage. And the immobility caused by corsets becomes chronic, so that even when the corset is taken off the lower ribs fail to expand. There can be little doubt that full vigour cannot be enjoyed by any woman who hampers the action of her lower ribs by a corset, even if the corset be not unduly tight. The corset not only impedes respiration directly, but it weakens the abdominal muscles, and thus indirectly weakens abdominal and diaphragmatic breathing, whose importance we have just seen.

Sir B. Ward Richardson thought the tight waist-belt even worse than the corset, and he gives a harrowing account of the evils of both: "Of the two evils to which I refer, the tight waist-belt is, I think, worse than the tight corset, except where the corset is so adapted that it acts at one and the same time as belt and compressor general. The effect of either is to press down upon the liver and stomach, to prevent the free circulation of the blood through these organs, to diminish their active physiological function, to make them descend and compress the vital organs that lie beneath them, and so to impair the growth and action of all the great secreting structures. The effect, again, is to interfere with the great breathing muscle, the diaphragm or midriff, which divides the chest from the abdomen, and which by its descent causes the lungs to fill in breathing. Lastly, the effect is to press upwards, and so to interfere with the heart and lungs themselves. An eminent Parisian physician, M. Breschet, recorded many years ago the facts relating to a woman who, on the right side of her throat, had a swelling which reached from the collar-bone to the level of the thyroid cartilage, and which, when the chest was tightly laced in corsets, was enlarged to its fullest. In the swelling the murmur of respiration could be heard when a stethoscope was applied over it; but when the chest was set at liberty and the swelling was gently pressed downwards, it disappeared. In this instance, a portion of the right lung had actually been forced behind the collar-bone, out of the cavity of the chest altogether, into the loose tissue of the neck. . . . I have seen many close approaches to it. I have several times known the lungs to be pushed quite out of place and compressed in the upper part of the thorax, and I have known the heart extremely displaced by the same pressure."

In children much harm is done by tight clothing even, apart from tight lacing.

There can be little doubt that many cases of defective chest development are due to the restrictions of clothing in children. Exercise of any kind that calls for deepened breathing tends to develop the chests of children; and development of this kind is much better than any development produced by any gymnastic exercises that pull on the chest by the arms. But in many cases children are so overclad or are clad in such tightly fitting garments that the chest cannot respond to the demands of the tissues for oxygen, and so exercise becomes impossible and the child's general physique, and especially its chest, suffers.

The tight clothing of infants is particularly deplorable. In his excellent book on "The Care of the Body," Dr. Francis Cavanagh writes: "Encircling the abdomen, is wrapped round after round of an interminable binder, also non-absorbent, and it is absolutely no exaggeration to say that the average man, when he first sees this binder applied, will turn giddy in sympathy with the infant as it is revolved and revolved and revolved in conformity with the needs of this appalling garment. The excuse for it is the prevention of umbilical rupture, and in a straining, struggling, crying child some support is needed; two folds of a more suitable substance would, however, be ample. Outside these articles are layer after layer of clothing equally ridiculous, and equally disconcerting to the child who has to don them. In the result the arms are left practically unprotected, the *thorax and abdomen are defrauded of possibilities of expansion*." Any impediment to respiration checks development both mental and physical, as is well seen in cases where breathing is hampered by the growths known as adenoids in the nasopharynx. A child suffering from adenoids is usually stunted and stupid; and the removal of the adenoids at once improves, sometimes in an amazing way, its physical and mental vigour. Therefore it is a matter of the very greatest importance that the garments of infants and children should be loose. In later life, when the development of the individual is finished, tight garments are not quite so pernicious; but still, by hampering the movement of the chest, they may temporarily or permanently reduce thoracic motility, and may render it impossible for the individual to derive due benefit from athletic exercise. In many instances the clothing of soldiers seems specially designed to impede respiration. He has been clothed hitherto, says Pembrey, "in open defiance of common sense and physiological principles. His tunic generally fits as tightly as possible, is made of thick material, and is fastened right up to the neck; his waist is hampered with a tight belt which interferes with abdominal breathing, and other straps supporting valise and haversack still further impede the movement of his limbs and body."

Even the tight garments so often worn by women in order to be in the fashion are bound to interfere with full respiration, and Dr. Cavanagh mentions that no less an authority than his savage majesty the King of Cambodia was of the opinion that "European women wear too many clothes. They should wear no more than two garments, one fitting close to the skin, the other covering the first. *Besides, they harness themselves too tight.*"

From every point of view loose and light garments are physiologically desirable. Not only do they give fair play to the heart and lungs, but they allow a certain amount of breathing by the skin, and they permit the access of cool air, which is perhaps the best stimulant of tissue change and respiration. The skin is meant to respond to changes of temperature: it is not meant to be kept in a hot-house at a steady temperature; it is meant to some extent certainly to be exposed to cold and heat and to modulate respiration accordingly. The first stimulus to respiration is often a stimulus from the skin, and all through life the skin is meant to play a reflex part in the mechanism of respiration. As we shall see later, lassitude of the skin is one of the commonest predisposing causes of colds, and many cases of deficient vitality are simply due to hampered respiration and pampered skin.

CHAPTER XV

ARTIFICIAL ATMOSPHERES

NO sooner did man begin to understand something about the mechanical and chemical properties of the atmosphere than he began to propose atmospheric modifications for medical purposes. No sooner, for instance, was the barometer invented by Torricelli in 1643, than a famous English physician of the name of Henshaw, who had grasped the principle of solution of gas under pressure, began to subject people to varying degrees of atmospheric pressure. He built a pneumatic chamber with an arrangement of bellows whereby he could increase or decrease pressure; and he even included a barometer whereby the pressure could be accurately gauged.

No sooner, again, did Priestley, Cavendish, Scheele, and Lavoisier discover oxygen than Dr. Beddoes, of Bristol, opened an institution for the inhalation of gases.

And no sooner, again, were the disinfectant properties of gases discovered than antiseptic inhalations came into vogue.

Naturally the poineers of aero-therapeutics were rather wild in their ideas. Henshaw treated even relapsing fever and similar diseases in his pneumatic chamber, and Beddoes thought he could cure consumption by an artificial atmosphere containing a reduced quantity of oxygen.

Yet though their ideas were rather wild they were on the right track, and aero-therapeutics has since grown into an important branch of medical science.

Indeed the subject is now so large that it is impossible in these pages to do more than outline its general principles.

Aero-therapeutics, in so far as it deals with artificial atmospheres, may be said to aim at producing beneficial physiological effects by artificially varying the pressure, temperature, humidity, and composition of the atmosphere.

In order to modify the *pressure* of the atmosphere some sort of an apparatus is necessary, and great ingenuity has been expended in the invention of mechanical contrivances. In a broad way mechanical contrivances may be of two kinds—either pneumatic cabinets, in which the whole body is immersed, or inhaling appliances which apply varying pressures only to the air-passages and lungs. Each apparatus has its advantages and disadvantages. In pneumatic chambers, and cabinets, pressure may be more easily kept steady, and the composition of the inhaled gas more easily kept constant; by an inhaling apparatus, on the other hand, the pressure can be more easily altered.

By means of either of these contrivances a variety of pressure effects may be produced. The patient may inspire rarefied or compressed gases, and expire them into gases rarefied or compressed.

We thus have at least four possibilities:—

Inspiration of—	Expiration into—
(1) Compressed	Compressed
(2) Rarefied	Rarefied
(3) Compressed	Rarefied
(4) Rarefied	Compressed

Methods (3) and (4) will obviously promote an interchange of gases in the lungs and will be useful where increased interchange is desirable. They will likewise be a means of massaging the respiratory mucous membranes. With the exception, however, of the inhalation of oxygen, which we will deal with separately, they are little used in general therapeutics. Method (2) which obviously simulates breathing at high altitudes is also little used, but would have the physiological and therapeutic effects already mentioned, *e.g.*, it would cause transitory flux of blood to the skin and mucous membranes, and would increase the number of the red blood corpuscles, while, if carried too far, it would produce dyspnœa and the symptoms of mountain-sickness. There remains method (1), the inspira- of compressed air with expiration into compressed air. This is probably the modification of atmospheric pressure conditions most used, and most useful, and we will now consider it in more detail. The increased pressure is generally provided by a pneumatic chamber, and does not as a rule, exceed 2 atmospheres. The physiological effects produced are partly mechanical and partly physico-chemical. The natural effect of the increased pressure is to augment the inspiratory force of the chest and to stretch the elastic tissue of the lungs. The chest therefore expands further and a greater volume of air is respired. At the same time the breathing and pulse-rate are slowed. Further, the blood in the skin and in the mucous surfaces exposed directly to the atmospheric pressure is reduced, and a correspondingly greater quantity of blood is sent to internal parts. The greater quantity of blood sent internally causes an increase in the secretion of urine. By a course of compressed-air baths the capacity of the chest may be more or less permanently increased.

The physico-chemical effects of compressed-air baths depend chiefly on the increased solution and absorption of oxygen—an increase associated in some way not quite understood with increased tissue waste and respiratory exchange. One notable effect of this is to increase the appetite; and divers who are, of course, subjected to great pressure, always illustrate this effect. If diet be not increased, those subjected to compressed air lose weight; and compressed-air baths are thus useful in the treatment of obesity.

The therapeutical applications of condensed air depend both on the mechanical and physico-chemical effects we have noted, and these effects are found particularly useful in acute and subacute inflammation of the respiratory mucous membranes. "If I were to be asked," writes Professor Oertel, "what remedy or what therapeutic procedure I considered the most efficacious in acute catarrhal inflammations of the respiratory mucous membrane, or of the mucous membranes directly exposed to the external air, I should unhesitatingly give the preference to the employment of the compressed-air chamber. We possess no remedy equal to it for antagonising the congestion, hypersecretion, and softening of the distended surfaces of the mucous membrane in the stage of catarrhal irritation, without itself acting as an inflammatory excitant."

Compressed-air baths are therefore beneficial in acute bronchitis, cold-in-the-head, inflammation of the pharynx and larynx. They act, in such cases, both by mechanically reducing the congestion of the mucous membranes, and by stimulating nutrition and tissue-change.

The disease, however, in which compressed-air baths are chiefly used is that disease of the lungs known as *pulmonary emphysema*. In this disease the air vesicles are dilated and to some extent destroyed, and the circulation of blood through the lungs and interchange of gases in the lungs is very defective. The result is breathlessness and chronic catarrh. Here again the entrance of large volumes of compressed air increases oxygen supply to the blood and gives great relief. Greater relief still is given sometimes if the compressed air inspired is expired into rarefied air.

In cases of consumption compressed air must be used with caution. In the earlier stages of the disease, or in cases where the lungs are insufficiently filled, it may do good; and in cases of arrested disease it may be a useful form of pulmonary gymnastics; but where there is acute disease or a tendency to hæmorrhage it might easily prove detrimental. The usefulness of compressed-air baths in cases of heart disease is a subject of debate; but they should certainly be used with caution in such cases.

We have spoken only of compressed natural air, but of course the compressed air may be altered in composition, moistened, mixed with foreign gases, and medicated in various ways.

Medicated Air.—In this connection medicated air may be considered. The idea that certain vapours and substances carried to the lungs by the air might be medicinal, is of very ancient origin. As early as the time of Homer sulphureous vapours were employed as disinfectants. Hippocrates was a firm believer in fumigation. Galen advised consumptives to live near Vesuvius and Etna, so as to inhale sea-air and sulphur-vapour.

Naturally, the discovery of germs and the spread of the antiseptic theory gave new impetus to this old idea, and during the last hundred years medicated inhalations have been used for a variety of purposes. Sometimes medical substances are inhaled as a fine dust; sometimes as gases; sometimes in the shape of a fine spray. Though the fact has been often doubted, it has been established that fine sprays and dusts can be inhaled into the very air-cells of the lungs, and can disinfect not only the larger air-tubes but also their ultimate subdivisions, and in cases of purulent secretion and of irritative conditions inhalations of antiseptic and of soothing medicaments may be very useful. There are no inhalations, however, which can actually kill germs of consumption, or of any other disease in the lungs, though it is possible they may prevent to some extent the spread of the disease.

Quite apart from any medicaments, the vapour of water given hot or cold has valuable therapeutic properties, and the steam-kettle has long held a place in domestic medicine. Even refrigerated and heated air can be used to produce useful physiological effects.

Oxygen Inhalations.—One of the most interesting and important of inhalations is the inhalation of oxygen. By the inhalation of pure oxygen, the same chemico-physical effects can be produced, so far as oxygen is concerned, as by the respiration of air, under a pressure of 5 atmospheres, and, of course, it is much more easy to obtain pure oxygen than to produce the atmospheric pressure mentioned. We have already mentioned the relationship between oxidation and the organism, and have pointed out that the demand of the tissues and not the supply of oxygen is the determining factor in the consumption of oxygen. Under normal conditions of rest and exercise the supply much more than meets the demand. It is not, therefore, possible to stimulate tissue change merely by offering more oxygen to the lungs or even by forcing more oxygen into the blood; and it is only when the supply of oxygen to the tissues is abnormally low, and when (as during violent exercise) its consumption is abnormally high, that oxygen inhalations can be of service. Even then, if oxygen be given at too high pressure it causes, as we mentioned in the previous chapter, inflammation of the lungs, or even convulsions and death; and it can be of service only if the means of transport are satisfactory. Thus the tissues of a man with anæmia or heart-disease may suffer from lack of oxygen; but it is futile to offer more oxygen at the lungs, since in the first case there are, so to speak, too few trucks to carry it, and in the second case, so to speak, too little engine-power. Oxygen is chiefly useful in cases where the heart-power is sufficient and the blood satisfactory, but where there is insufficient oxygen pressure in the air-cells, *e.g.*, in cases where the chest wall is deficient in mobility, or where there is some impediment to inspiration and expiration. It is useful accordingly in emphysema, bronchial catarrh, asthma, and such-like troubles.

In cases where the oxygen supply is normal, but the oxygen consumption excessive, *e.g.*, in cases of violent exercise where both the lungs and heart are working hard to supply oxygen to the greedy tissues. In such cases oxygen inhalation is of less service; but still, in some instances it may be useful.

Last summer the well-known physiologist, Professor Leonard Hill, made experiments on athletes which would seem to prove that the muscular energy of healthy individuals may be increased by inhalations of oxygen. He gave inhalations of oxygen to runners, before short races, and found that they could make better times and run with less fatigue than formerly. The well-known runner, Mr. T. H. Just, describes his experience as follows: "On Monday, July 27th, I ran some trials on the Stamford Bridge ground. For some few minutes previous to starting I inhaled oxygen, standing at the starting-point. Immediately afterwards I started and ran half a mile. I covered the first quarter-mile in 54 sec.; and completed the half-mile in just inside 1 min. 55⅛ sec. This is faster than I had run a half-mile before, my previous best performance being in a race, when I did 1 min. $55\frac{4}{5}$ sec. In practice I have previously never done better than 1 min. $58\frac{1}{2}$ sec. After a short time I ran a quarter-mile, having again inhaled oxygen. This quarter took $53\frac{3}{5}$ sec. The first part was slow, but the last 260 yards were covered in 30 sec., and I finished strongly. Shortly afterwards I ran two separate 100 yards, going quite easily in about $11\frac{3}{5}$ sec.

"Whilst running I felt extremely light on my feet, running for the most part with very little exertion. A remarkable fact was that after running my legs were not at all stiff, as they usually are after a hard run; after the quarter they were as supple and springy as if I had not run at all. Even though I had to run much within a very short space of time, I did not feel in the least tired.

"I travelled so easily that the pace seemed much slower than it really was; and even sprinting, which usually tires me very much, seemed quite easy, although I had just run a half- and a quarter-mile. I might add that I had been smoking considerably for three days previous to the trial, and that in the week before I had run three 800-metre races, and so my condition probably erred upon the stale side.

"In conclusion, I might say that I felt no after-effects at all."

Mr. H. E. Holder, another runner, also succeeded in beating his former best times, and "he noticed the absence of distressful dyspnœa, of 'grogginess,' and of stiffness of the legs, and was able to run again with unusual ease."

As a result of these experiments the experimenters concluded "that athletes have every hope of materially shortening the record times and accomplishing greater feats by the use of oxygen, or deep breathing beforehand."

To inhale oxygen *during* a race might be a difficult matter, but, in the paper from which we quote, the suggestion is made that "it would be quite easy to place a low awning over a portion of the track, through which the runners could run, and under which oxygen might be allowed to escape as the runners came to it. Thus a few breaths of oxygen could be inhaled at each lap. . . ."

Later in the year Professor Leonard Hill reported a further experiment by Mr. Martin Flack on Wolffe, the swimmer, who was attempting to swim the Channel. "Wolffe refused the help of oxygen till he was so far done that he talked about coming out, and was thoroughly disheartened. On breathing oxygen the done-up man, who was wasting his breath in talking, quieted down, his breathing become slower and less distressed, he stopped talking, and plugged away again in workman-like fashion." Professor Hill also made experiments on workmen lifting weights, on a Marathon runner, and on himself, and found in all cases that inhalations of oxygen increased power of work. Some of his most instructive experiments were made on horses. He proved, on the one hand, that ordinary working horses were able to do more work after the administration of oxygen; and on the other hand, that on race-horses in the perfection of condition oxygen had no effect. In the case of the race-horses "the muscular, circulatory, and respiratory systems were built up to the perfection of their working powers," and between the power of the muscles of the legs and body to do work; and the power of the breathing muscles and heart to supply oxygen there was such perfect co-ordination that even on a 6-furlong race plenty of oxygen could be supplied by the natural mechanism of respiration and circulation. In the case of the common horse, on the other hand, the respiratory and circulatory functions were not equal to the task of supplying as much oxygen as the muscular system required; and hence an extra supply of oxygen became necessary. The moral of all this is that the weaker the respiratory power in proportion to the muscular power, the more useful will inhalations of oxygen be, and Professor Hill, therefore, who had had a "tobacco heart," and whose respiratory capacity was diminished, found oxygen inhalations especially useful.

When Jabez Wolffe failed to cross the Channel, his failure was apparently due to exhaustion of the respiratory muscles which work the thorax, otherwise oxygen could not have given such marked relief. The account given by Dr. Martin Flack, who accompanied the swimmer, shows how lacking in oxygen the blood must have been at the point when oxygen was administered. "The pilot," writes Dr. Flack, "held the mouthpiece to the swimmer, while M. F. manipulated the cylinder and watched the effect of the gas. This was, to say the least, somewhat striking. The effect of a dyspnœic 51-inch chested man at the end of a tube of oxygen is perhaps not easily appreciated at first. The bag was emptied with such amazing rapidity and completeness that a leak seemed probable, and a big leak too. A leak indeed there was, but careful inspection showed that it was only into the alveoli of an oxygen-starved man." Now, the relief given by the oxygen showed that the circulation was comparatively all right—that the heart and swimming muscles had still energy which required only oxygen for its realisation, and that the lack of oxygen in the blood was due simply to deficient ventilation of the lungs resulting from weakening of the thoracic movement. It might accordingly be thought that strength and energy might be indefinitely extended by the administration of oxygen. But this is not the case. The final cause of failure of muscular energy is failure of nerve energy, and no administration of oxygen can prevent this failure. The benefit derived from oxygen can be only temporary, and will be marked only if the cause of failure is not so much general nerve exhaustion as exhaustion of the nerve-centres and muscles which have to do with the ventilation of the lungs. It must be understood that oxygen does not create energy, but that it is only a condition of its realisation.

Before leaving the subject of oxygen inhalations it may also be interesting to mention that, by a combination of forced breathing and oxygen inhalations, Dr. Vernon was able to hold his breath for the extraordinary time of 8 min. 13 sec., showing how much excess of oxygen it is possible to add to the blood, or rather—to be physiologically accurate—showing how much carbon dioxide it is possible to remove; since it is excess of carbon dioxide in the blood and not lack of oxygen that compels respiration.

CHAPTER XVI

CLIMATE

THE word "climate" (from κλίνειν, to incline) had reference originally to differences in the amount of sunshine received in different latitudes owing to the inclination of the earth's axis. Claudius Ptolemy, author of the "Ptolemaic System of the Universe" (A.D. 120–149) divided climate into zones "in which the length of the longest day increased successively by half an hour between the Equator and the Arctic Circle." This was a very irregular division, for on this principle the first zone embraced 8½ degrees of latitude and the twenty-fourth only $\frac{1}{20}$ of a degree.

The word "climate," however, soon came to have a much wider meaning and to connote other atmospheric phenomena besides temperature.

Climate as now understood was defined by Humboldt as "all the changes in the atmosphere which sensibly affect one's physical condition." This definition is obviously too vague and too broad, and Hann's definition of climate as "the sum total of the meteorological phenomena that characterise the average condition of the atmosphere at any one place on the earth's surface," is more satisfactory.

The daily meteorological mean with respect to the temperature, density, humidity, &c., of the atmosphere we talk of as "weather," the seasonal or annual mean we talk of as "climate."

The meteorological factors temperature, humidity, barometric pressure, sunshine, &c.—which go to the making of climate, have already been separately discussed, and we shall now only deal briefly with the classification of climate and describe a few climatic types.

To make a definite geographical classification of climate is found to be an impossible matter, for the various meteorological factors that signify climate vary in a very irregular and independent fashion. Thus we find the greatest heat to be north of the Equator, and we find that altitude has almost as much to do with heat as latitude.

We can, however, make a general classification of climates. We can roughly divide climates into types—into tropical and temperate, and cold climates, and we can divide tropical and temperate and cold climates into dry and moist.

Tropical climates may be defined as those in which the average temperature exceeds 70° F.

Temperate climates may be defined as those in which the average temperature exceeds 50° F.

Cold climates may be defined as those in which the average temperature is below 40° F.

Such a subdivision so far is of little physiological or therapeutical value. An average temperature of 70° F. in India and an average temperature of 70° F. on the African Karroo have very different physiological meanings. Likewise a temperature of 20° F. at Peterhead and 20° F. at Davos have very different climatic meanings.

When, however, we further subdivide the climates into dry and humid we greatly increase the value of the classification. Thus we know at once that a tropical humid climate is exhausting and debilitating and that a cold dry climate is invigorating, and that a temperate humid climate may be soothing. As a rough classification of climate accordingly the following might be useful :—

Tropical—average temperature over 70° F. ...	*a.* Moist. *b.* Dry.
Temperate—average temperature between 40° and 60° F.	*a.* Moist. *b.* Dry.
Cold—average temperature below 40° F.	*a.* Moist. *b.* Dry.

One of the best and most useful of classifications of climate is that proposed by Dr. Huggard in his work "Climatic Treatment." It is as follows :—

CLASSIFICATION OF CLIMATES.

GROUP I.

CLIMATES WHERE THE HEAT DEMAND (OR DEMAND FOR TISSUE CHANGE) IS EXCESSIVELY SMALL.

Meteorological Characters—	*Physiological Characters*—
Hot climates: temperature over 71·6° F. (22° C.)	Demand for heat and for tissue change so small that there is difficulty in getting rid of the heat formed by the healthy body when production is at its lowest.

a. Heat Demand (or Demand for Tissue Change) Regular.

Dry: mean relative humidity under 60 per cent.	Fluctuations in heat demand fairly regular and comparatively small.

b. Heat Demand (or Demand for Tissue Change) Irregular.

Not dry: mean relative humidity over 60 per cent.	Fluctuations in heat demand irregular and comparatively great.

Wind largely increases the heat demands made by atmospheric humidity, but does not greatly increase the heat-removing power of dry hot air.

GROUP II.

Climates where the Heat Demand (or Demand for Tissue Change) is Small.

Meteorological Characters—	*Physiological Characters—*
Warm climates: temperature 60·8 to 71·6° F. (16 to 22° C.)	Demand for heat small, but such that heat normally produced can be easily removed.
a. Heat Demand (or Demand for Tissue Change) Regular.	
Dry: mean relative humidity under or about 66 per cent. (from 72 per cent. at 16° C. to 60 per cent at 22° C.)	Fluctuations in heat demand regular and controllable by clothes and shelter.
b. Heat Demand (or Demand for Tissue Change) Irregular.	
Not dry: mean relative humidity over 66 per cent.	Fluctuations in heat demand irregular and not easily controlled.

Wind intensifies the heat-removing action of atmospheric moisture but increases only slightly the heat-removing action of dry warm air.

GROUP III.

Climates where the Heat Demand (or Demand for Tissue Change) is Medium.

Meteorological Characters—	*Physiological Characters—*
Temperate climates: temperature 48·2 to 60·8° F. (9 to 16° C.).	Medium or normal heat demand for white races.
a. Heat Demand (or Demand for Tissue Change) Regular.	
Dry: mean relative humidity under or about 75 per cent. (from 78 per cent. at 9° C. to 72 per cent. at 16° C.).	Fluctuations in heat demand moderate in amount and regular, except in so far as they depend on wind, and then controllable.
b. Heat Demand (or Demand for Tissue Change) Irregular.	
Not dry: mean relative humidity over 75 per cent.	Fluctuations in heat demand irregular and relatively large in amount. Fluctuations due to wind not easily controlled.

Wind intensifies the action of moisture in removing heat, especially at the lower temperatures.

GROUP IV.

CLIMATES WHERE THE HEAT DEMAND (OR DEMAND FOR TISSUE CHANGE) IS LARGE.

Meteorological Characters—	*Physiological Characters—*
Cool climates: temperature 33·8 to 48·2° F. (1 to 9° C.).	Large demand for production of heat.

a. Heat Demand (or Demand for Tissue Change) Regular.

Dry: mean relative humidity under or about 79 per cent. (from 80 per cent. at 1° C. to 78 per cent. at 9° C.).	Fluctuations in heat demand regular, and moderate in amount, except in so far as they depend on wind, and then controllable.

b. Heat Demand (or Demand for Tissue Change) Irregular.

Not dry: mean relative humidity over 79 per cent.	Fluctuations in heat demand irregular, relatively large in amount, and not easily controllable.

Wind greatly intensifies the action of low temperature and of atmospheric moisture in carrying off heat. Clothing gives efficient protection against dry, but not against cold air.

GROUP V.

CLIMATES WHERE THE HEAT DEMAND (OR DEMAND FOR TISSUE CHANGE) IS EXCESSIVE.

Meteorological Characters—	*Physiological Characters—*
Cold climates: temperature under 33·8° F. (1° C.).	Very large demand for production of heat.
The mean relative humidity at the temperatures included in the present group is usually high, about 80 per cent. or more; but the absolute humidity is so small that the relative humidity has little physiological significance except indirectly through its action on cloud.	Fluctuations in heat demand considerable, generally fairly regular, and for the most part under control, except in so far as they depend on wind.

Wind enormously increases the heat-abstracting power of a low temperature.

These categories would serve roughly to indicate climates of certain broad types; but in selecting climates for therapeutical purposes classifications are of little value, since the ultimate selection must require in most cases not a few broad features such as a classification indicates, but a detailed specification. What is required in climatology is not a logical classification of places according to their broad climatic *resemblances*, but a detailed study of each with special reference to their *differences*. What is required is a special study of different individual typical climates, *e.g.*, the climate of Davos, the climate of Sidmouth, the climate of some part of the Sahara or Karroo. The greatest mistakes are made by advising climates on *broad* principles. Thus a patient is advised to go to the Canary Islands because the climate there is dry and equable; but the Canary Islands is a big word, and the climate of Guimar, for instance, is very different from the climate of Orotava. Or a patient is sent to some place on the South African Karroo because it is dry and hot to find when he gets there that it is intolerably dusty or too high for his heart. If climatology is to be of therapeutical value it must individualise in climates.

It is perfectly true that in some cases a classification indicates just the broad climatic feature we require to know. Thus if a place be classified as a high hill station, it informs one that it had best be avoided by people with weak hearts, and that it may be useful in cases where expansion of the lungs is desirable.

Here we shall briefly discuss only High Alpine Climates, Desert Climates, the Climate of the Sea, since these seem to us the only climates sufficiently distinct to deserve consideration as types.

High Alpine Climates.—By a high Alpine climate we mean the climate in Europe at a height somewhat above ordinary cloud-level. All climates at such a height, though varying in detail, will have certain characteristics. The air will be less dense and drier than air at sea-level, solar radiation and terrestrial radiation will be more active, the air will have less dust and fewer germs than at lower levels, and more radio-activity. The electric potential will be higher. There will be rapid changes of temperature with extremes of hot and cold. The climate of Davos which is typical of such climates is thus described by E. Frankland: "The summer climate of Davos is very similar to that of Pontresina and St. Moritz, in the neighbouring valley of the Engadine—cool and rather windy; but so soon as the Prättigan and surrounding mountains become thickly, and for the winter permanently covered with snow, which usually happens in November, a new set of conditions come into play, and the winter climate becomes exceedingly remarkable. The sky is, as a rule, cloudless or nearly so; and as the solar rays, though very powerful, are incompetent to melt the snow, they have little effect upon the temperature, either of the valley or its enclosing mountains; consequently there are no currents of heated air; and, as the valley is well sheltered from more general atmospheric movements, an almost uniform calm prevails until the snow melts in the spring.

"Even when the temperatures in the early morning are from −15° to −20° the invalids at Davos go out to walk soon after sunrise (9 to 10 a.m.) without any special wraps, and many of them even without overcoats. The sky is dark blue, and in the strong sunshine one feels comfortably warm when sitting in front of the hotel with a thin coat on. The rarer atmosphere conducts less heat away from the body, even apart from the effect of the calm. Furthermore, there are no minute watery particles in the air to make it damp and chilly, as at lower altitudes. In addition to this, the direct radiation from the sun together with the heat due to reflection from the snow, give a temperature in mid-winter which is occasionally almost unbearable when one is sitting still in the sunshine."

DAVOS-PLATZ.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Mean temperature $\frac{7\frac{1}{2} + 1\frac{1}{2} + 2 \times 9\frac{1}{2}}{4}$	−7·4	−4·9	−2·7	2·1	6·6	10·1	12·6	11·7	8·7	3·4	−1·5	−6·4	2·6° C.
1867–1900	18·6	23·18	27·14	35·78	43·88	50·18	54·68	53·06	47·66	38·12	29·3	20·48	36·68° F.
Mean absolute humidity, 1867–1900, in mm. ...	2·29	2·64	3·00	4·12	5·35	6·92	8·09	7·92	7·00	4·66	3·44	2·53	4·82 mm.
Mean relative humidity, 1867–1900	8·3	80	79	76	72	75	75	81	79	79	82	84	79 per cent.
Cloudiness in tenths of the sky, 1867–1900 ...	4·0	4·5	4·9	5·6	5·5	5·7	5·2	5·0	4·8	5·0	4·6	4·7	5·0
Rain and snowfall in mm. of water 1867–1900	46	54	53	57	58	102	126	125	94	67	55	61	898 mm.

Snow in cm.: In year 1902 = 672 cm.; in year 1903 = 607 cm.
Average number of days per year in 30 years (1867–96) on which rain or snow fell = 140 days.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Days with percentage of possible sunshine, 1886–1900—													
Clear days (75–100 per cent.) ...	13	13	12	10	8	8	12	14	13	14	13	13	143 } 200
Slightly cloudy (50–75 per cent.) ...	4	3	5	6	7	5	5	6	4	4	4	4	57 }
Cloudy (25–50 per cent.)	4	3	5	5	6	7	6	4	5	4	3	3	55
Covered days (0–25 per cent.) ...	10	9	9	9	10	10	8	7	8	9	10	11	110

Wind, 1903	Calm	N.E.	S.W.	S.	E.	S.E.	N.	W.	N.W.
Three observations daily	719	262	61	25	15	7	3	0	0 times.

The table on opposite page is from Dr. Huggard's work, "Climatic Treatment."

An Alpine climate is tonic and stimulating. Dr. Huggard well says: "Other things being equal, that climate is most tonic which demands the greatest amount of tissue change that an organism can permanently yield," and it is certain that the dry cold must cause a quickening of tissue change in order to keep up the bodily temperature. It is possible also that the increased electric potential and the increased radio-activity and the greater actinic power of the sun may also exercise a stimulating effect. The air, being comparatively free from dust and germs and thoroughly isolated, is particularly free from irritating contents, and permits the healing of ulcerations on the respiratory mucous membranes and other exposed surfaces. The dryness and rarity of the air also tend to dry up catarrhal and inflammatory discharges from mucous surfaces; but catarrh of the larynx is sometimes aggravated by the dry cold air. The rarity of the air causes deeper inspirations, and thus is useful in expanding parts of the lungs otherwise too little exercised. The rarity of the air likewise causes a compensatory quickening of the heart.

Dr. Huggard recommends high Alpine climates in cases of incipient phthisis, bronchial catarrh, asthma, convalescence after acute diseases, anæmia, neurasthenia. Diseases of the circulatory system, however, are often aggravated by the rarefied air.

It is probable that the benefits derived from a high altitude are due to the altitude only in so far as increased altitude means increased sunlight, better spirits, drier and cooler air, radio-activity, and so forth; and has very little to do with decreased air pressure *per se*. The Cornish miners, who live under an increased air pressure, compare quite favourably in health and physique with the Alpine peasants, and many of the Swiss peasants who live an indoor life are very anæmic and grow old early. It must be recognised, too, that though the dry cold air is a stimulant to metabolism, it is a futile and may be a pernicious stimulant, if the digestion be not stimulated also so that fuel may be provided for the fire.

It has been found in experiments mentioned elsewhere that rarefaction of the air causes an increase in the number of the red blood-cells; but it is very doubtful whether such increase is permanent; and some observers are of the opinion that altitude eventually causes anæmia. In this connection we may quote Mosso's opinion and his opinion of Alpine climates in general.

"An evident proof," he says, "that the blood does not become more abundant at great altitudes, is easily obtainable by all mountain-climbers who will examine the colouring of the skin and mucous membranes in those individuals who live on the high Alpine pastures. One often meets with poor creatures who spend several months of the year in some lonely valley herding their sheep and goats at heights above 2,500 metres. I have never found one of these individuals who had the flourishing look of the shepherds and peasants of the plain. Their skin is of an earthen colour, their outward aspect almost inclines one to think that Jourdanet was right in his theory of anæmia caused by altitude.

Many physicians send their patients into the mountains in the hope that they will recover more speedily owing to an immediate rarefaction of the air. I, too, believe that an Alpine climate may exercise a favourable influence in the case of invalids, if they do not go beyond an altitude of 2,000 metres, but this is not because the deficiency of oxygen gives rise to a reaction within the organism and to an increase of blood corpuscles. The treatment by altitude resembles the hydropathic treatment in its processes and in its effects, only that instead of shower-baths and plunge-baths, we have the sharp air, the wind, and the sun which act on the body. Other factors in the treatment by altitude are light and motion which modify the circulation of the blood and lymph, the Alpine surroundings, the obligatory following of the rules of treatment, the more hygienic and natural mode of life."

It does not seem to have been noted that, the rate and depth of breathing remaining the same, the tension of the alveolar carbon dioxide will be lowered at high altitudes, and that this lowering together with quickened action of the heart will tend to increase *production* of carbon dioxide and will thus lead at first to an increase in activity. As soon, however, as the breathing accommodates itself to the altitude and restores normal alveolar carbon dioxide tension the tendency will be for a diminution in metabolism owing to lessened oxygen tension, unless the heart do extra work or unless the red blood-cells be increased in number.

Probably after a time the various factors affecting metabolism compensate for differences in each other and life goes on very much the same as at sea-level.

Desert Climates.—High Alpine climates are dry and *cold:* desert climates, on the other hand, are dry and *hot.* Like Alpine climates, desert climates imply a rapid circulation of water through the tissues, but owing to their heat they are relaxing in their summer season.

In their winter season, however, the heat is moderate; and the dry air may be quite bracing. The writer, who is particularly sensitive to heat, found that on the African Karroo he felt quite active and energetic even when the sun temperature was 130° F., or more. The rapid evaporation of perspiration keeps the skin cool, and the dry air seems in some way to aid the respiratory exchange; for even at a height of 4,000 or 5,000 feet, in hot, dry air, climbing seems to be less effort, and to tax heart and lungs less than in England at sea-level in much cooler air.

There seems little doubt that the drying power of the desert air does, in some way, aid the healing of tubercular ulceration of the lungs; but its healing efficacy must not be exaggerated, for it must be remembered that the natives of the desert often contract tuberculosis in a most acute and virulent form; and it must be remembered too that many patients who have done badly in desert climates have regained strength and vigour in the damper English climate. A too dry climate, or rather a climate with too great drying capacity, seems in time to have an exhausting effect on the European constitution, and those who live inland in desert places find a change to the seaside most refreshing. The extreme summer heat of the African desert is certainly most enervating and there can be little doubt that many lives have been lost by a compulsory summer sojourn on the South African Karroo. Indeed, simply because Egypt is easier to reach and easier to leave it will always be a much more valuable health resort than South Africa. One marked advantage of a desert climate is the cool nights and the marked difference between the day and the night temperature. Herein it greatly excels such a dry and equable climate as, say, the climate of Tenerife. It is a popular superstition, based on a wrong theory of colds, and malaria, and suchlike, that an equable climate is a healthy climate. Except for the very old and debilitated, a climate with considerable variations in temperature is much more bracing and much more stimulating to the processes of metabolism on which vitality depends. It is probably partly the changes of a dry climate that give it its bracing character, and the extremes of temperature in America may help to account for the energy of the American. The Irishman in the dry, stimulating, change-able American climate is a much more active animal than in his own damp, equable island.

The desert dust is a factor hardly favourable to health; but the dust is aseptic, and the writer suggests that in cases of pulmonary disease it may aid healing by stimulating fibrosis. In cases of tubercular disease of the larynx, however, it is undoubtedly harmful, and no "throat case" should ever be sent to dusty desert localities.

Egypt is the most convenient desert climate for Europeans, and Dr. Huggard describes its climate thus:—

"The winter climate of Egypt is marked by great regularity, as compared with European climates. There are fewer of those violent changes from the weather of one day to the weather of the next than are to be found in perhaps any other countries resorted to by invalids. Nevertheless the daily oscillation of temperature is considerable, amounting commonly to from 17 to 25 or even 36° F. Occasionally the daily range of temperature is as low as 8° F., and occasionally it exceeds 40° F.

"Owing to the greater dryness of the air these oscillations of temperature are more marked at Assouan and at Luxor than at Cairo, at Helouan, or at Mena House. In all the Egyptian stations the mornings and evenings are cool—it may be even cold—while the day from eleven to three or four o'clock is distinctly warm. This alteration of temperature is one of the charms of Egypt, making the heat bearable, and giving a sense of buoyancy and elasticity to the inhabitants.

"Luxor may be taken as being roughly 4° F. warmer than Cairo, Mena House, or Helouan; and Assouan as 5° F. warmer than Luxor. The mean daily range of temperature in the months from December to March for two years was the same at Luxor and at Assouan, namely, 28·5° F., while at Helouan it was 22·3° F.—that is, 6° F. less The relative humidity is 15 or 20 per cent. lower at Assouan than at Mena House or at Helouan. Assouan has more wind than Helouan, but is less dusty than Luxor, and probably also than Helouan or Mena House.

"The number of days in the year on which rain occurs at Cairo varies from about nine to seventeen, nearly all in the spring and winter months; and the rainfall is only little more than an inch. At Alexandria rain is two or three times as frequent, and six or seven times as much in amount. Rain occurs less frequently at Mena House and at Helouan than at Cairo, and rarely at Luxor and Assouan.

"The average relative humidity in the hours from 10 a.m till 6 p.m. for the four months from December to March was at—

"Mena House	Helouan	Luxor	Assouan
51·7	42·7	36·3	30·5."

Climate of the Sea.—By the climate of the sea we mean the climate experienced at sea during a long voyage. As regards temperature, a long sea voyage may sometimes be considered to include various climates, but all sea voyages have certain distinctive climatic characters in common—the general climatic characters of the ocean—and may, therefore, be considered as a single and separate climatic type.

The temperature in the Bay of Biscay and the Red Sea, the temperature in Baffin's Bay and in the Gulf of Mexico may differ widely, yet in every case the climate is moist and equable, and varies comparatively little from day to day, and in every case the air is laden with salt, free from dust and germs, and in more or less rapid motion. Go where we will at sea, we shall never find a dry climate with great differences between the temperature of day and night, or between the temperature of one day and the next; and we shall never find the dust and germs and vapours which are found on land.

In the fastest steamers changes in daily temperature may come comparatively quickly; but even so the changes are not so rapid as upon land. The following temperatures are the temperatures taken on board the ship *Sobraon* between the Cape of Good Hope and London, and by taking every third day one will get an idea of the progressive changes from cold to heat and from heat to cold again on board a steamer:—

60·6° F.	63·2°	63·7°	67°	65·4°	67·5°	70·1°	72·2°	72·9°
76·6	75·13	75·4	77·3	78·2	78	76·8	80·7	81·5
83·5	82·6	81·5	85	78·5	80·7	82·5	81·5	74·6
79·5	78·3	77·3	75·1	73·5	74·9	73·5	75·4	74·5
75·2	75·7	74·3	73·6	73·6	71·4	71·1	67·6	67·2
65·5	68·7	68·5	65·5	68·3	68·7	67·6	68·6	64·5
60·5	57·9	56·9	—	—	—	—	—	—

The temperatures are noon temperatures, and it will be noticed that increase and decrease are both gradual.

The health-giving properties of a sea voyage have always been recognised. It might be thought that so much humidity would be pernicious, but, as we have seen, humidity is harmful chiefly by preventing heat-loss, and the sea-breezes do much to counteract this influence.

Dr. W. S. Wilson, in his book "Ocean as a Health Resort," gives the following reasons for the healthfulness of a sea voyage:—

"1. The entire change of scene, and the enforced rest from customary occupations.

"2. The facilities for being constantly in the open air during the greater part of the twenty-four hours.

"3. The habitual respiration, when on deck, of air free from those organic and inorganic impurities, and floating particles of dust and carbon, that are met with in even the purest air on land.

"4. The presence in the air of certain substances such as saline particles, which may exert a specific beneficial effect upon the lungs and air-passages, also probable differences in the electrical conditions of the atmosphere and in the amount of ozone in the sea-air.

"5. The greater equability of temperature at sea.

"6. The sedative influence exerted on the constitution by a comparatively humid atmosphere combined with a high barometric pressure.

"7. The bracing and hardening effect of almost constant sea-breezes, and of the changes of climate experienced in passing through the different 'regions' of the ocean."

As a rule appetite is stimulated at sea, and the voyager gains weight; but during the hotter weather there may be considerable loss. The following interesting figures are given by Taylor in an article "On the Ocean as a Health Resort in Phthisis" (*Medical Chronicle*, 1885):—

WEIGHTS OF PASSENGERS TAKEN AT INTERVALS OF ABOUT A FORTNIGHT DURING A VOYAGE TO AUSTRALIA.

Second Weighings. Lat. 28° N.

CLASS I.—Healthy persons, or those suffering from minor complaints.
CLASS II.—Phthisical patients.

CLASS I. Number weighed, 32.

19 gained 64½ lbs., averaging 3·4 lbs.; 8 lost 11 lbs., averaging 1·4 lbs.; 5 neither gained nor lost.

CLASS II. Number weighed, 20.

12 gained 28 lbs., averaging 2·33 lbs.; 5 lost 9½ lbs., averaging 2 (nearly); 3 neither gained nor lost.

Third Weighings. Lat. 5° N.

CLASS I. Number weighed, 36.

5 gained 9 lbs., averaging 1·8 lbs.; 27 lost 99 lbs., averaging 3·66 lbs.; 4 neither gained nor lost.

CLASS II. Number weighed, 15.

3 gained 6½ lbs., averaging 2·16 lbs.; 12 lost 54½ lbs., averaging 4·54 lbs.

Fourth Weighings. Lat. 39–38° S.

CLASS I. Number weighed, 33.

25 gained 54·5 lbs., averaging 2·18 lbs.; 5 lost 12·5 lbs., averaging 2·5 lbs.; 3 neither gained nor lost.

CLASS II. Number weighed, 14.

8 gained 24 lbs., averaging 3 lbs.; 3 lost 6 lbs., averaging 2 lbs.; 3 neither gained nor lost.

TOTAL VARIATION BETWEEN FIRST AND LAST WEIGHINGS.

CLASS I. Number weighed, 38.

29 gained 162·5 lbs., averaging 5·6 lbs.; 9 lost 24·5 lbs., averaging 2·73 lbs.; greatest gain, 13 lbs.

CLASS II. Number weighed, 17.

9 gained 78 lbs., averaging 8·66 lbs.; 8 lost 16·5 lbs., averaging 2·06 lbs.; two greatest gains were 20 lbs. and 19 lbs.

Cases that benefit chiefly by a sea voyage are cases of neurasthenia and general debility, especially if the conditions be due to overwork. At sea it is difficult to overdo either physical or mental exercise and the complete rest in the fresh air, combined with freedom from business and professional worries, often works wonders.

To send, however, cases of acute mental depression to sea without a companion is a great mistake. The first day or two at sea the passenger is exposed to the risk of sea-sickness, and even if he escape that ailment he is apt to be lonely and misses the comforts of shore and has too much time to brood.

A still greater mistake is it as a rule to send consumptives for sea voyages. There is the risk of rough weather with confinement in a stuffy cabin to be considered; there is the further risk of unsuitable food. "An equinoctial gale," as Taylor points out, "is not unusually met with before getting away from our coasts, with all its concomitant miseries of sea-sickness and enforced confinement to the lower regions, with its draughts or want of ventilation, the deck being probably too wet and slippery for anything but a struggle to the smoking-room with its vitiated air." Granted good conditions—fine weather, suitable food, an airy cabin, a well-selected route and a well-selected early case a voyage may prove beneficial; but there are always risks, and as a rule the patient will do better on shore. In many cases patients are sent haphazard for an ocean voyage, and they are not unfrequently sent through the Red Sea and die on the way. The writer who has been several long voyages has seen several consumptives committed to the sea, and very few really benefited by the voyage.

Change of Air.—In this connection the question of "change of air" may be considered. When people speak of "change of air" what do they mean, and has "change of air," in any sense of the term, the mysterious virtues it is supposed to possess? A man feels run down and he goes, say, from Clifton to Brighton, or from Manchester to Margate, or from London to Ballachulish, or even from Richmond to Hampstead, for a "change of air," and returns feeling fresh and invigorated. He may have had a cold hanging about him for weeks, and in a day or two the "change of air" banishes it. He may have suffered from insomnia, and "change of air" makes him sleep; he may even have incipient phthisis, and "change of air" seems to annihilate the bacilli. In most cases the nature of the change seems unimportant: it may be from Richmond to Hampstead or from Hampstead to Richmond; it may be from Margate to Manchester or from Manchester to Margate; the change is equally efficacious. The belief in the efficacy of a "change of air" is almost universal. Let us see what is the basis of the belief. In what does the change of air consist? We have seen that apart from artificial pollution the compostion of the air is remarkably uniform—always about

21 per cent. oxygen and 79 per cent. nitrogen, and about ·03 per cent. carbon dioxide. The chemical composition of the air—artificial pollution apart—in most cases is not changed by change of locality. Yet the air in many cases does seem changed. The air at Margate, quite apart from any benefit it may bestow, seems different from the air at Sidmouth. In what does the difference consist? The difference seems to consist chiefly in difference in humidity: it is largely a question of "saturation deficit." If the saturation deficit be larger metabolism is stimulated, and the general feeling of energy is increased; if it be smaller metabolism is diminished, and there is a feeling of lassitude and languor. In either case there is considerable physiological change which is likely enough to cause an alteration in the health, both in direct and indirect ways. A drying air by cooling the skin stimulates metabolism; but at the same time by abstraction of moisture from the body it may cause constipation.

A similar difference is found in the matter of wind. A change from a windy to a windless, from a windless to a windy climate is a change which necessarily implies physiological change owing to different degrees of abstraction of heat.

Again, if the change be a change to a higher or lower altitude we have physiological changes produced by the difference in barometric pressure. And likewise we may have physiological changes produced by increase or decrease of sunshine and in temperature.

The term "change of air," therefore, has definite physiological significance, and change of air has definite physiological results; but it is not—as the public suppose—a matter of chemical change so much as a matter of change in the humidity, movement, pressure, temperature, sunniness of the atmosphere.

A "change of air" is undoubtedly a most valuable therapeutic weapon, and a weapon that often reaches to the root of the evil even when used very much at random.

To discuss here in full the principles which should guide one in changing air would be simply to recapitulate much of the preceding chapters, but in a general way if a change is meant to be stimulating or bracing a windy and if possible high and dry climate should be chosen, while if a sedative effect be required as in cases of excitement, or insomnia, or sensitiveness to changes of climate a sheltered humid climate should be chosen.

In a general way, too, if simply a *change* is required, a place should be chosen involving as many atmospheric alterations as possible. Thus a person may be sent from the Isle of Wight to North Berwick or from Exeter to Davos with the certainty that the change will be stimulating.

In some cases change of air seems to produce more constitutional alteration than any of the factors we have mentioned would seem capable of producing, and there may be potent factors of climate such as radio-activity of which we know very little. But a change of air, it must be remembered, means a change of many things—a change in food, in scenery, in mental enviroment. A man who goes from Manchester to Margate goes not only from polluted to pure air, but usually from a sedentary indoor to an active outdoor life. A man who goes to sea gets not only sea-breezes but freedom from business correspondence, not only change of air but change of scene. The wise physician in prescribing change of air sees that his prescription contains other changes, besides change of air.

CHAPTER XVII

THE GASES OF THE ATMOSPHERE—THEIR DISCOVERY

THE natural gases of the air—oxygen, nitrogen, and carbon dioxide—are so subtle, so tasteless and odourless, that for centuries their chemical importance, like their mechanical potency, was unsuspected. Their intimate relationship with the processes of life was of course known, but the conception of the relationship was mystic and vague, as shown in the connotation of such terms as *spirit*. The first theories of air, indeed, made it the crude substance out of which the soul was concocted: it was breathed into the heart, and after a first refinement there, into "vital spirits," was carried in part to the brain, where it was manufactured into still finer spirits—the "animal spirits."

The belief in the middle of the seventeenth century is concisely put by Dr. N. Henshaw, who writes in 1644 that: "The commonly received opinion is that respiration serves chiefly for cooling the heart, next that it yields matter for the production of vital spirits, and lastly that it discharges the lungs of a fuliginous excrement which seems to transude from the mass of the blood into the branches of the rough artery," and makes the interesting suggestion that the main object of respiration is "to squeeze the blood out of the lungs into the heart."

The theory is stated more fully by Foster, thus: "In the first place the air introduced by breathing served to regulate, to maintain, and at the same time to temper, to refrigerate the innate heat of the heart, that fire which, placed in the heart at the beginning, continued there all life long and was the one source of the warmth of the body. In the second place the pumping action of the chest served to introduce into the blood the air which was necessary for the generation in the left side of the heart of the vital spirits which were thence distributed over the body by the arteries. In the third place the same action served to get rid of the fuliginous vapours, the products of the innate fire burning in the heart. Both the pure air engendering the vital spirits, and the foul vapours, the effect of the heart's labours, were supposed to pass by the vein-like artery, the pulmonary vein, the one one way the other the other."

The idea of chemical action of the air in respiration was evidently very vague and inchoate at this date; and the chemical action of the air in any other respect, *e.g.*, in combustion, was equally a matter of misty surmise.

The discovery of carbon dioxide and the invention of the term "gas" by Van Helmont was a small step towards the light; but a much greater step was taken by his contemporary, the young French doctor, Jean Rey, who gave the first hint of the possibility of air entering into combination with solid bodies. It was only a hint perhaps, but if it had been taken it would have saved a hundred years. This is his story. The Sieur Brun "having placed two pounds six ounces of fine English tin in an iron vessel, heated it strongly on an open furnace for the space of six hours with continual agitation and without adding anything to it, he recovered two pounds thirteen ounces of a white calx, which filled him at first with amazement, and with a desire to know whence the seven ounces of surplus had come." It was a difficult problem, and one cannot but admire the courage and prescience and imagination of the young French doctor who maintained that the increase in weight was due to accretion of air. "To this question, then, I respond and sustain, proudly resting on the foundations already laid, 'That this increase in weight comes from the air, which in the vessel has been rendered denser, heavier, and in some measure adhesive.'" Well might he conclude: "Behold now this truth, whose brilliance strikes the eye which I have drawn from the deepest dungeons of obscurity. This it is to which the path has been hitherto inaccessible. This it is which has distressed with toil so many learned men who, wishing to know it, have striven to clear the difficulties which held it encircled. Cordon, Scaliger, Fachsius, Cæsalpinus, Libavius have carefully sought it, but never perceived it. Others may be on its quest, but vainly if they fail to follow the road which I, first of all, have made clear and royal: all others being but thorny footpaths and inextricable byways which lead never to the goal. This labour has been mine; may the profit be to the reader, and to God alone the glory."

Such was his pæan; but, alas! the road he made "clear and royal" remained untrodden for many a long year.

Some sixty years later that mighty genius Robert Boyle published his "Memoirs for a General History of the Air." About this time the composite nature of the air began to be suspected; it was no longer considered to be a simple homogeneous substance as taught by the ancient philosophers, but rather, in the words of Boyle, "a confused aggregate of different effluvia." Boyle made many shrewd experiments and shrewder surmises; he prepared such gases as hydrogen and carbon dioxide; and he suggested that the air contained some special substance or substances necessary for flame and for life. But he made little use of the road of Jean Rey by which later experimenters reached so far.

His friend Robert Hooke and Richard Lower, went a step further in showing that air was taken up by the blood in the lungs, and that the blood was thereby brightened in colour, and Borelli of Pisa and Sylvius of Leyden about the same time also recognised that particles of air were mixed with the blood in the lungs and were necessary to life. Hooke also made the very shrewd surmise that flame is due "to a substance inherent in and mixt with air, that is like if not the very same with that which is fixt in Salt-peter;" and Sylvius suggested that the action of air on the blood was due to certain "nitrous and subacid parts" of it.

The greatest advance, however, made about this time, was made by the brilliant Oxonian, John Mayou, who in 1674 published four very remarkable tracts dealing with air and respiration. This brilliant thinker was the first clearly to teach that the air had a special constituent necessary for combustion and respiration. The special constituent he calls sal-nitro-aereum, or spiritus nitro-aereus, or igneo-aereus, and there is no doubt he meant by these terms the gas later called oxygen. There is perhaps nothing in the whole record of science more interesting than his exposition of his views; but here we shall only quote a few passages to show his extraordinary acuteness. Having shown that the food of flame is not the air as a whole but certain particles in it which are also contained in nitre, he proceeds to make the following comparison between breathing and burning:—

"If a small animal and a lighted candle be shut up in the same vessel, the entrance into which of air from without be prevented, you will see in a short time the candle go out; nor will the animal long survive its funeral torch. Indeed, I have found by observation that an animal shut up in a flask together with a candle will continue to breathe for not much more than half the time that it otherwise would—that is, without the candle. Nor is it to be supposed that the animal in such a case is suffocated by the smoke of the candle, since if the flame be supplied by the burning of spirits of wine no smoke is produced (and yet the animal dies); moreover, when a candle is used the animal lives for some time after the candle has gone out and its smoke has disappeared, so that we cannot suppose that it is suffocated by the smoke.

"The reason why the animal can live for some time after the candle has gone out seems to be as follows. The flame of the candle needs for its maintenance a continuous and at the same time a sufficiently full and rapid stream of nitro-aereal particles. Whence it comes about that if the succession of nitro-aereal particles be interrupted even for a moment, or if these are not supplied in adequate quantity, the flame presently sinks and goes out. Hence so soon as the igneo-aereal particles begin to reach the flame scantily and slowly it is soon extinguished. For animals, on the other hand, a lesser store of the aereal food is sufficient and one supplied at intervals, so that the animal can be sustained by the aereal particles remaining after the candle has gone out. Here it may be remarked that the movements (expansions) of the collapsed lungs not a little help towards the sucking in of the aereal particles which may remain in the said flask and towards transferring them into the blood of the breathing animal." This is surprisingly accurate; but even more surprising is the accuracy of this theory with regard to the relationship between breathing and muscular activity. "Now it is very probable," he says, "that this aereal salt is wholly necessary for all muscular movement, so that without it the beat of the heart cannot take place. For we have reason to think that the sudden contraction of a muscle is due to particles of two different kinds mixing with each other, and mutually acting upon each other. Now we cannot suppose that both kinds of particles, the effervescence of which gives rise to the contraction of muscles, can come from the mass of the blood, for liquids which are derived from the same source unite again without any effervescence. So that it seems that something extraneous is requisite for bringing about the ebullition which leads to muscular movement.

"We may therefore suppose that the nitro-aereal particles derived from the inspired air supply the one class of motive particles which, meeting with the other salino-sulphureous particles furnished by the mass of blood, but dwelling in the motor structures, excite that effervescence which gives rise to muscular contraction, as we have fully shown elsewhere. The movement of the heart is carried out in the same way as in other muscles.

"Hence when breathing is stopped, since that aereal salt needful for all movements is lacking, the beat of the heart, and therefore the flow of the blood to the brain, are interrupted, and death necessarily follows." Further he explains that breathing is increased during violent exercise, not in order that a greater flow of blood may take place freely through the lungs, but in order to provide for the greater expenditure of the nitro-aereal salts in many of the effervescences taking place in the contraction of the muscles."

Mayou also realised the relationship between breathing and bodily heat, and taught that even plants breathed. Still one more point we must notice before leaving this genius. He at least set foot on the "clear and royal" road of Jean Rey; for he notes that antimony when burned by sun's rays increases in weight. "Now," he says, "we can hardly conceive that the increase of weight of the antimonium arises from anything else than from the igno-aereal particles inserted into it during the calcination." The most important part of Mayou's contribution to the chemistry of the atmosphere is summarised by Sir William Ramsay as follows: "The atmosphere consists of particles of two kinds of gas at least: one of these termed 'nitro-aerial particles' is necessary for the support of life and for the combustion of inflammable bodies; while the other, left after this constituent has been removed, is incapable of supporting either life or combustion. The portion which is necessary for life enters, during respiration, into the blood. It is the chief cause of motion in animals and in plants."

One would think that when John Mayou had got so far that the further chemistry of air would be quickly solved; but, alas! the truth he sowed fell on stony soil and came to nothing. He wrote, as we said, in 1674, and for sixty years after that date there was retrogression, not progress. His generalisations were not accepted, and a false theory of combustion which held that all combustible bodies contained a substance known as "phlogiston," prevented an impartial consideration of facts.

In 1732 Stephen Hales concluded that "our atmosphere is a *Chaos*, consisting not only of elastick, but also of unelastick air-particles, which in plenty float in it, as well as the sulphureous saline, watery, and earthy particles which are no ways capable of being thrown off into a permanently elastic state, like those particles which constitute true permanent air." But nevertheless he pleaded that this "now fixt now volatile Proteus" should be considered among the "chemical principles," "notwithstanding it has hitherto been overlooked and rejected by chymists as in no way entitled to that denomination."

If in 1732 the chemical function of air was dubious, and its composition a chaos, it is evident things had not progressed much since the time of Mayou. Nevertheless light was at hand; for only twenty years later Joseph Black did much to elucidate the composition of air by proving that it contained as one constituent the gas carbon dioxide. As has often happened in the history of science, his discoveries were made in the course of apparently irrelevant investigations. He had undertaken a course of experiments on magnesia as a remedy for stone, and found that it lost weight on heating through the escape of a volatile constituent. The volatile constituent was of course carbon dioxide, and in the course of his investigations he discovered that this gas (which had been previously artificially obtained by Van Helmont and many others) was also contained in the atmosphere. He found that a solution of quicklime attracted particles of this gas from the atmosphere, and came to the conclusion that quicklime attracted not ordinary air but a particular kind of gas in the air. "Quicklime, therefore, does not attract air when in its most ordinary form, but is capable of being joined to one particular species only, which is dispersed through the atmosphere, either in the shape of an exceedingly subtile powder, or more probably in that of an elastic fluid. To this I have given the name of *fixed air*, and perhaps very improperly, but I thought it better to use a word already familiar in philosophy than to invent a new name, before we be more fully acquaint with the properties of this substance which will probably be the subject of my further inquiry."

Black showed that this gas could be poured from one receptacle into another, and that it extinguished flame. He further identified it with the gas produced by fermentation, by burning charcoal, by breathing, and he surmised that fire and breathing had something to do with its production.

Dr. Joseph Black, then, showed that air contained carbon dioxide. Twenty years later a student of his, Dr. Daniel Rutherford, discovered nitrogen. Sir William Ramsay in his book, "The Gases of the Atmosphere," states Rutherford's achievement as follows: "He removed the oxygen from ordinary air by combustibles such as charcoal, phosphorus or a candle; and having got rid of the carbon dioxide, in those cases when it was formed, by alkali or lime, he obtained a residue, now known as nitrogen."

Rutherford is usually considered the discoverer of nitrogen, but it was prepared by Cavendish in the same year in exactly the same way. He describes it thus: "The specific gravity of this air was found to differ very little from that of common air; of the two it seemed rather lighter. It extinguished flame, and rendered common air unfit for making bodies burn in the same manner as fixed air, but in a less degree, as a candle which burned about 80 seconds in common air mixed with the same proportion of this burnt air."

A little later Priestley and Scheele discovered oxygen, the third of this great trio of gases.

On the 1st of August, 1874, Priestley heated red oxide of mercury by means of a burning glass, and collected the gas given off. He found that the gas supported combustion better than ordinary air and that mice could live longer in it. He obtained the same gas from "nimium" and from "red precipitate," and was satisfied that it "had all the properties of common air, only in much greater perfection, so as to be entitled (according to my idea of purity or impurity with respect to air) to the name of dephlogisticated air, which, for that reason, I gave to it." The quotation will show that though he prepared oxygen and set free from an oxide the same igneo-aereal substance that Mayou had combined as an oxide, yet that he did not realise the nature of his discovery and considered oxygen not a constituent of air, but merely very free from phlogiston "between four and five times as good as common air." He did not realise the place of oxygen in the air, and he quite misconceived its function in respiration.

It is interesting to note that Priestley inhaled the oxygen he prepared. "My reader," he says, "will not wonder that after having ascertained the superior goodness of dephlogisticated air by mice living in it, and the other tests above mentioned, I should have the curiosity to taste it myself. I have gratified that curiosity by breathing it, drawing it through a glass syphon, and by this means I reduced a large jar of it to the standard of common air. The feeling of it to my lungs was not sensibly different from that of common air, but I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that in time this pure air may become a fashionable article in luxury. Hitherto, only two mice and myself have had the privilege of breathing it."

Scheele was a greater chemist than Priestley, and had obtained oxygen a year earlier than this English chemist, by heating various substances. It is interesting to notice that Scheele calls his oxygen "fire-air." Many of Scheele's experiments were exceedingly acute and ingenious, but, like Priestley, he was blinded by the phlogiston theory and was unable to interpret his facts correctly.

It was left to the great Lavoisier to make obscure things plain. He began his work in 1772—the same year in which Scheele found his fire-air, and strangely enough he began on the "clear and royal" road of Jean Rey by repeating Mayou's explanation of the gain in weight of substances when burned. In 1772 he reported to the French Academy of Sciences as follows: "About eight days ago I discovered that sulphur, when burned, instead of losing weight gains weight; that is to say, from one pound of sulphur much more than one pound of vitriolic acid is produced, not counting the moisture gained from the air. Phosphorus presents the same phenomenon. The increase of weight is due to a great quantity of air which becomes fixed during the combustion, and which combines with the vapours. This discovery, which I confirmed by experiments which I regard as decisive, led me to think that what is observed in the combustion of sulphur and phosphorus might likewise take place with respect to all the bodies which augment in weight by combustion and calcination; and I was persuaded that the gain in weight in the calx of metals proceeded from the same cause."

This, of course, was merely a resuscitation of the views of Rey and Mayou and might have led to equally little; but two years later Priestley told Lavoisier of his experiments with precipitate and red lead, and the French chemist proceeded not only to confirm them but also to explain them, and in a few years he had practically solved the problems of the chemical composition of air and of the nature of combustion and respiration. In a paper published in 1777 he distinguished between the three kinds of gases, oxygen, nitrogen, and carbon dioxide, calling them "pure air," "azote," and "acide crayeux." Not only so, but he recognised that carbon dioxide was produced by the union of carbon and "pure air." In a paper published about the same time he dealt with the respiration of animals, and showed the resemblance between combustion and respiration. He also showed that the oxygen was the important respiratory constituent of the air and that it was partly converted into carbon dioxide by the process of respiration. Finally, in his treatise "Traité élémentaire de Chimie," he tells how he formed red precipitate by heating mercury in air, and then by again heating separated the oxygen from the red precipitate.

With Lavoisier air became a definite group of chemical gases; and only a few minor gases and details were left for after investigators; and no further great discovery was made till 1894, when Sir William Ramsay and Lord Rayleigh discovered in the air a new gas which they called *argon*. This gas had been surmised by Cavendish; but it remained for these two great modern chemists to prove its actual existence.

In seeking for compounds of argon Sir William Ramsay further found a gas called helium in a mineral called cleveite, and the same gas has since been found in other minerals and mineral waters. The gas had been previously detected by spectroscope in the sun.

The existence of the two gases argon and helium made it almost certain that, in accordance with Mendeléeff's law, other gases still must exist, and chemists began to hunt diligently for them.

In 1898 they were found. In that year, by means of an elaborate distillation of liquid air, Sir William Ramsay showed that the air contained not only argon and helium, but also three other gases which he named neon, krypton, and xenon.

Still there was more to follow, for Madame Curie's discovery of radium led to the discovery that air contains radioactive substances and gases which may be of a great vital importance.

Such then, in brief, is the history of the discovery of the gases of the atmosphere.

CHAPTER XVIII

OPEN-AIR TREATMENT OF CONSUMPTION AND OPEN-AIR SCHOOLS

THERE is no fact in the ætiology of diseases more certain than that "the longe-woo cometh oft of yvel air," or to put it in modern English, that tuberculosis is often a disease of bad ventilation. The discovery is at least as old as Hippocrates, and is just what common sense might expect, since consumption is a disease due to germs sometimes present in the air, and since bad ventilation both increases opportunities for infection and decreases vital resistance to disease.

The evidence against impure air is twofold. In the first place, consumption is found to increase *pari passu* with impurity of air. Those who work in the open air are much less liable to consumption than those who work in indoor vitiated air. Fishermen, gardeners, gipsies, hunters, trappers, engine-drivers, sailors, coachmen, agricultural labourers, nomad tribes are all comparatively free from tuberculosis; while clerks, and publicans, and printers, and shopkeepers contract it much more frequently.

Overcrowding may be taken as a rough measure of impure air, and the following table shows how the death-rate from consumption rises as overcrowding increases:—

London—Proportion of Population living more than Two in a Room (in Tenements of less than Five Rooms.)	London—Average Annual Death-rate from Phthisis per 100,000 of Population, 1894–98.
Districts with under 10 per cent.	111
„ „ 10–15 „	144
„ „ 15–20 „	161
„ „ 20–25 „	177
„ „ 25–30 „	209
„ „ 30–35 „	231
„ „ over 35 „	259

In the second place, consumption has always diminished as ventilation has improved. Thus, "it is stated that where the cubic feet in printing-rooms fell below a certain number per head, 12·5 per cent. of the printers (compositors) had consumptive symptoms, with larger space the numbers fell to 4·35, and with further enlargement to 2 per cent." Again, the death-rate from consumption in Canadian barracks was at one time 23 per thousand and fell with improving ventilation to 9 per thousand and then to 6 per thousand.

It is unnecessary to adduce more evidence: it is voluminous; and it may be accepted as a proven fact that bad air plays a very important part in the ætiology of consumption.

Equally certain is it that in the treatment of the actual disease pure air is of the greatest curative value. Hippocrates, Galen, Sydenham, and many other old physicians had knowledge of this fact, and the open-air verandahs in the temples of Æsculapius in which the sick were treated, were precursors of the modern sanatoria.

But for centuries open-air treatment had little vogue, and it required the efforts of McCormack, Bodington, Brehmer, and Walther to convince the public that open windows are not quite so dangerous as they were supposed to be, and that even in the worst weather exercise in the open air is desirable.

We have time here merely to hint at the theory and practice of these pioneers.

In 1840 Dr. George Bodington, of Sutton Coldfield, published his essay "On the Treatment and Cure of Pulmonary Consumption on Principles Natural, Rational, and Successful." In this essay Bodington criticises the mode of treatment prevalent which consisted "in shutting the patients up in a close room, to exclude as far as possible the access of the atmospheric air; and thus forcing them to breathe over and over again the same foul air contaminated with the diseased effluvia of their own persons." "What," he asks, "could rationally be expected to be the result from such practice, than that of the conversion of a slow or moderate consumption into an intense or galloping one?" And he boldly declares: "The only gas fit for the lungs is the pure atmosphere freely administered, without fear; its privation is the most constant and frequent cause of the progress of the disease. To live in and breathe freely the open air, without being deterred by the wind or weather, is one important and essential remedy in arresting its progress—one about which there appears to have generally prevailed a groundless alarm lest the consumptive patient should take cold." "The patient," he says, "ought never to be deterred by the state of the weather from exercise in the open air; if wet and rainy, a covered vehicle should be employed, with open windows. The cold is never too severe for the consumptive patient in this climate; the cooler the air which passes into the lungs, the greater will be the benefit the patient will derive. Sharp frosty days in the winter are most favourable. The application of cold pure air to the interior surface of the lungs is the most powerful sedative that can be applied, and does more to promote the healing and closing of cavities and ulcers of the lungs than any other means that can be employed."

It was a most audacious heresy to preach; but Bodington did more than preach, he put his theories into practice, and proved them sound. Not only so, he actually advocated the modern sanatorium system. "The generality of the medical profession have not the opportunity of thus treating their consumptive patients; if they are to succeed, they should have country houses in proper situations, well ventilated, and provided with all appliances and means to boot, where their patients should be under their own eyes, and strictly watched and regulated in all respects as regards exercise, air, diet, medicine, &c.; or there should be a certain class of practitioners who should exclusively pursue this practice as a distinct branch, to whom those in the large towns should confide their consumptive patients, instead of sending them, as many now do, to take their chance, or probably to fall into the hands of mercenaries at some distant seaport where they commonly die, far away from friends and home.

"With respect to the consumptive poor patients—those who cannot afford to pay for a proper treatment of this sort—hospitals should be established in the vicinity of large towns, in fit situations and properly appointed in all respects for their reception and treatment."

Bodington was certainly a man of courage and prevision; but the seeds he sowed fell upon thorny soil.

In 1855 Dr. Henry MacCormac, of Belfast, published a tract entitled "Consumption, as Engendered by Rebreathed Air," and preached very much the same doctrines as Bodington. His pathological theory that rebreathed air was "the real, the *vera causa*, indeed the *causa sine qua non* of tubercular disease in its every guise and form," and that tubercle was effete unoxidised carbon, was perhaps not sound; but his advocacy of open-air treatment was eloquent and convincing and his practice bold and successful. Listen to this. "People cannot do well with windows closed, and so far at least as they are thereby constrained to respire air already breathed, they sicken and they perish. The window closed by night entails greater destruction than sword or gun. It is the most baleful of agencies, the almost exclusive begetter of consumptive, scrofulous, tuberculous disease. No epidemic, no war, not even wars and epidemics combined slay half so many. How people shriek and lament and exclaim when these destroyers are upon them, and yet with what unruffled complacency and satisfaction do they look upon their stuffy, carpeted, airless chambers, with closed sashes and casements, which prove the greatest destroyers of all." . . . "Once when in the English lake district, where I saw many a pallid foul-air-poisoned countenance, I was asked to look at a young girl whom I found labouring under scrofulous articular disease—in a word, tubercle of the hip. I tried to make the truly anxious mother aware of the serious character of her child's malady, its real nature and actual origin. But when I further entreated her to carry the young sufferer into the sun's light without, and to admit the fresh free atmosphere within, she declined utterly. Of some repulsive drug she would give what you pleased, but as to renewed air, she would have none of it. And yet during the nights I spent there, the sweet wild winds from the hills about swept without let or hindrance through my chamber. . . ."

There was no timidity, no half-heartedness about MacCormac's views. "For, as I must incessantly iterate," he says, "it is the indoor, not the outdoor exposure which we are to dread. Wind, wet, rain, cold, coupled with wholesome vigorous effort, are Nature's sharp restoratives, maintain health, cheerfulness, and vigour—blessings on no other terms to be enjoyed."

Again, "The windows, whether French or English, qualified indeed by the degree and direction of the wind, should be thrown largely and freely open by night particularly both in summer and winter. Nor drifting wind, nor damp, nor rain, nor snow, although of course to be guarded against, are to be dreaded as is confined air."

Yet again: "People as yet are undecided, and indeed it is yet a matter of uncertainty, as to the best means of effectively securing house ventilation by day. At night, however, there is no difficulty or ambiguity whatever about the matter. It is only necessary more or less, according to the state of the wind, to pull down the window freely, and, except when dressing and undressing, to keep it down winter and summer and always. With warm, abundant night coverings there is not a shadow of risk. There is none of rheumatism, none of bronchitis—in short, no risk whatever."

MacCormac was evidently an enthusiast, and had the courage of his convictions; but his theory of "carbonæmia" was against him, and he made more enemies than converts.

It was in Germany that the open-air treatment of consumption first took root. About the very time that MacCormac published his tract, Dr. Hermann Brehmer started a sanatorium at Görbersdorf, and in 1888 Dr. Otto Walther started his famous Nordrach Colonie in the Black Forest, and these two German doctors must be considered the fathers of the modern sanatorium treatment, which has done so much to spread the cult of the open window.

Now all over the world sanatoria are legion.

Open-air Treatment of Consumption.—Open-air treatment of consumption is a triple treatment by air, food, and exercise, and we shall now consider it briefly and broadly under the three heads—air, food, exercise.

1. *Air.*—A patient suffering from consumption requires pure air. He requires pure air because impure air means air rich in microbes which may infect his diseased pulmonary tissue, and cause suppuration and rapid breaking down. He requires pure air because impure air, as we have seen, is enervating. This much will be conceded by all without argument. But then the question arises, How much pure air, and at what temperature? It is here that open-air treatment becomes distinctive and original. Up till the time of McCormac and Bodington and Walther pure air was administered timidly and half-heartedly. The patient was told that he must open his window a few inches at the top but that he must avoid damp and cold and draughts, and must not go out in bad weather. He was kept in a room at a comfortable equable temperature, and in winter was sent to Madeira, or the Riviera, or Torquay, or some similar warm climate.

But modern open-air treatment, under the lead of the three pioneers we have mentioned, has become much more drastic and audacious. Instead of a window open 3 inches at the top, it encourages windows wide open, and prefers French windows so as to have more window space. Instead of fearing breezes in the room, it recognises that gentle breezes, whether indoors or outdoors, are healthy and invigorating. It believes in thorough perflation instead of in stagnant air. Day and night, winter and summer, hot and cold, wet and dry, all windows are open. There is no question about whether the carbon dioxide should be 9, or 10, or 13 parts in 10,000, for it is present indoors in just the same proportions as outdoors. There is no question of microbes, for the rooms are kept dustless, and any microbes that may enter are quickly attenuated by light and air. There is no question of maintaining a steady indoor temperature, for the indoor temperature varies with the outdoor temperature, and may—as in Davos—be 80° F. at 12 noon, and perhaps 100° lower at 12 midnight.

The treatment certainly is drastic and audacious, but it affords circumstantial evidence in favour of the views of ventilation we have maintained in the last chapter. Simply because the draughts are large enough to circulate more or less equally all round the body, and because the rooms are dustless, "colds" during the open-air treatment are almost unknown, and when they occur they seem always due to imported infection. Nor is it a case of being "hardened," as some seem to think. Patients come from fires, and shawls, and screens, and double windows, and other hothouse luxuries, and go straight to a barely furnished, windy room with wide-open windows, and *they do not catch cold.* The wind may blow around their beds, the temperature may be below freezing, yet they do not catch colds. Some foolish and inexperienced people propose that patients should begin open-air gradually by opening windows a few inches at first. But that is not to begin gradually, it is not to begin at all. The open window is wide open for two reasons—firstly, to avoid the pernicious draught produced by a window open for a few inches; secondly, to cause a sensible circulation of air.

The results of open-window ventilation are extraordinary. Night-sweats and fever go, appetite returns, cough decreases, muscular and nervous tone are improved. These are the results of open windows, and these results do not follow when a window is opened 3 inches in a dusty room. The fact of the matter seems to be that perflation is necessary not only that the air may be pure, but also in order that the metabolism of the body may be stimulated by the wind playing upon the skin. We know the potent vaso-motor effect of wind—of heat and cold; we know how wind blowing on the face may revive a fainting person; we know how the very first breath of life may be evoked through skin reflexes, and we are driven to the conclusion that a very important factor in open-window treatment is the mechanical and thermal stimulus of the air blowing on the skin. The importance of this mechanical and thermal stimulus is well seen in the fact that patients, whose night-sweats persist in spite of open windows so long as their beds are at a distance from the window, lose the night-sweats at once if their beds are moved up to the window. The importance of the thermal stimulus is also suggested by the fact that patients usually make more progress in winter than in summer, and that improvement also usually follows a reduction in the amount of clothing worn.

It is possible that in consumption, perflation may have an additional value in blowing away poisonous products which might otherwise be inhaled. All those who have experience of consumptive cases know the characteristic mousy odour of their skins, and it is very possible that this emanation, whatever it be, has toxic qualities.

It may be said that the discomfort of open windows is almost intolerable, and that the remedy is worse than the disease; but the discomfort is greater in imagination than in reality. For a great part of the year open windows are a delight and not an affliction, and those who keep them open find the stagnant atmosphere of rooms with closed windows most oppressive. And though, during the English winter, open windows must involve a certain degree of discomfort, yet the discomfort is not so great as it might seem, and is much lessened by a little extra food and clothing.

Still, those who are elderly and debilitated, and who are incapable of rapid metabolism even under the stimulation of cold, will often find it desirable to carry out the open-air treatment in warmer and drier climates, such as Egypt and Tenerife.

Here we may discuss the question of damp. A rainy climate does not necessarily mean a humid climate—a climate where warm air is constantly near saturation point; but even a humid climate is much less pernicious than is commonly supposed. In the very dampest parts of England or Ireland patients will do well if they lead a consistently open-air life. The evil reputation of damp, indeed, is due just to the fact that it means, as a rule, closed windows just at a time when the walls and roof are least pervious to air, and when there is least wind and when open windows are most required. If any one compare his sensations indoors with windows shut in damp, wet weather and in dry weather, he will find the rooms stuffier in damp, wet weather.

Nevertheless, a dry climate is better than a damp one, because, as we have already seen, it stimulates water flux and tissue change; and, other things being equal, open-air treatment in dry air will be both more pleasant and more beneficial than in a damp one.

2. *Food.*—"The stomake eke of eire is overtake." Between food and breathing there are both mechanical and chemical relationships. Mechanically, heavy food in the stomach may impede circulation, and may prevent free movement of the diaphragm, and therefore it is well not to take violent exercise too soon after a heavy meal. Chemically, the nature of the food affects the chemical nature of the respiratory exchange. Thus, after a meal rich in carbohydrates, there is an increase in the amount of carbon dioxide discharged by the lungs.

But the relationship between food and air is even more intimate than this. Air may quite legitimately be considered food; for a time, at least, the oxygen of the air enters into chemical association with the elements of the tissues derived from food; and though the association is unstable, yet it may endure for a considerable time. Hibernating animals, though eating nothing, may actually gain in weight during their winter sleep, simply through the oxygen their tissues take up; and the oxygen remains quietly in the combination till they waken.

The chief object, indeed, of the oxygen inspired is to enter into such a combination, and, unless there be material with which to combine, it is useless to send oxygen round the body in the blood.

The combination formed is unstable and explosive, and when it breaks down it gives rise to heat and energy; but it cannot be formed, and so heat and energy cannot be produced, unless the food have its part of the combination ready. It follows, accordingly, that during fasting the consumption of oxygen decreases, and that after food the consumption of oxygen increases. When Wolff in his cross-Channel swim grew cold, and failed to produce heat and energy after inhalation of oxygen, it was probably food that was required—nothing else. Much oxygen is useless without food, and much food is useless without oxygen; but the organism is wise, and if we give it more food it takes up more oxygen, and if we give it more oxygen it cries out for more food. It may seem a strange thing to aver, but it is true that the lungs can, perhaps, be best filled and developed by filling and developing the stomach. This is a point to be noticed—that food develops the breathing capacity.

The result of open-air treatment is to stimulate metabolism, leading to increased ingestion of food, and increased acquisition of oxygen. The swing of the pendulum of life is lengthened; there is more breaking down; but there is also more building up, and all excretions and secretions are correspondingly increased. Increased, no doubt, also are the secretions of the cells which form natural antitoxins, and thus the microbes of the disease are directly attacked.

The stimulation of the appetite by fresh air is very striking. Even a slight improvement in ventilation may have a pronounced effect.

Reid, in his well-known work on "Ventilation," gives an account of a very amusing experiment he made in this direction. "Some years ago," he writes, "about fifty members of one of the Royal Society Clubs dined in an apartment I had constructed, where, though illuminated by gas, the products of its combustion were essentially excluded, as they were all removed by a ventilating tube connected with, but concealed in the drop of the Gothic pendant in which the central lights were placed. Large quantities of a mild atmosphere were constantly supplied, and passed in quick succession through the apartment throughout the whole evening, the effect being varied from time to time by infusing odoriferous materials, so that the air should imitate successfully that of a lavender field, of an orange grove, &c. Nothing very special was noticed during the time of dinner by the members, but Mr. Barry, of the British Hotel, who provided the dinner, and who, from the members of the Club being frequently in the habit of dining at his rooms, was familiar with their constitutions, showed the committee that three times the amount of wines had been taken that was usually consumed by the same party in a room lighted by gas, but not ventilated—that he had been surprised to observe that gentlemen whose usual allowance was two glasses, took without hesitation as much as half a bottle—that those who were in the habit of taking half a bottle took a bottle and a half, and that, in short, he had been compelled twice to send hackney-coaches for additional supplies during dinner, though he had provided a larger supply than usual, considering the circumstances under which the members met.

"Minute inquiries afterwards assured me that no headache nor other injurious consequence had followed this meeting, nor was any member aware at the moment that they had partaken more heartily than usual till Mr. Barry showed them what had taken place."

It may be interesting to note in the same connection that when the ventilation of the barracks was improved it was found necessary to increase the rations of the men, and there is a story told of seamstresses who applied against better ventilation, since it increased their appetites beyond their means.

If even an improvement in ventilation improve the appetite, the perfect ventilation of open-air treatment may be expected to work wonders—and work wonders it certainly does. Patients who have experienced no appetite for months, and who have been eating only enough to support a sparrow, quickly, as a rule, acquire the appetite of a hungry Hottentot.

Since the appetite is due to the fanning of the fire of life and associated with a vigorous metabolism, and also probably with the formation of anti-toxins, it should be encouraged until the patient has gained a weight considerably over his normal weight. But care should be taken not to exhaust the patient's nerve-energy by overworking his digestive system, and care also should be taken not to fatten the patient to such an extent as to impede his heart and respiration.

The nature of the food matters little so long as it is digestible, and so long as proteids and carbohydrates are mixed in due proportions. Milk, eggs, bread, butter, meat, and plenty of them, are all that is required.

3. *Exercise.*—The question of rest and exercise is so closely connected with the question of air and food that it may be briefly considered here. A man resting in the open air may usually be readily fattened. We have seen as much as 9 lbs. gained in a single week, and a stone increase in the first month is nothing exceptional. It is, however, the aim and object of open-air treatment not only to make patients stout, but to make them muscular and strong, and with this end in view regular slow walking exercise is prescribed, provided always the patient's temperature be not unduly high. If the temperature, which is a fair index of the activity of the disease, be too high, rest on a couch or in bed is necessary; but as soon as possible exercise must be begun in order to aid healthy metabolism and to strengthen the heart. It is not sufficient, as many patients think, simply to live in the open air, and to eat and grow fat; it is necessary to attain the maximum of health and vigour possible for the patient, and this cannot be attained without suitable exercise under medical supervision and with due regard to pulse and temperature.

We have seen a patient, through the ignorance and obstinacy of friends, kept at rest for months till all his muscles, including the muscles of his heart, were in a flabby and atonic condition. With exercise the patient would probably have become strong enough to throw off the disease; as it was his recovery was retarded and his life endangered. On the other hand, many patients do too much and wear out their strength. It is absolutely essential that patients with temperatures above a certain point should rest, and it is also absolutely essential that questions of rest and exercise should be decided by a watchful and experienced physician.

This, of course, is a most cursory sketch of the open-air treatment; for this is not the place to describe it in detail.

There can be no doubt at all that open-air treatment can be best carried out in a specially constructed building under special medical supervision. A sanatorium is built in such a way as to facilitate the freest perflation, and it is furnished in such a way as to prevent any possible accumulation of dust. At a sanatorium, too, hygienic rules are laid down which must be kept, and the patient escapes from the fussy interference of friends and from all temptations and excitements. He has regular meals, regular rest, regular exercise, and his energy is conserved and increased in every possible way. At home or in any private house it is almost impossible to carry out the drastic treatment successfully, and every patient who can afford it should always spend at least a few months at a sanatorium that he may be educated in the treatment. There are now many good sanatoria for paying patients all over England.

Sanatoria for the Poor.—Sanatoria for the poor perform most valuable medical and educational functions. They not only save or prolong a certain number of lives, but they also teach the class which most needs teaching the value of fresh air, and the precautions which should be taken against infection. "Hence," says Newsholme, "it is a great mistake to regard sanatoria as merely cure-places. They are schools of national importance." On the other hand, they are a very costly weapon of warfare against disease, and it is probable that the money spent on sanatoria might have been more profitably spent in improving the housing of the poor and in starting open-air schools. Two of the most unsatisfactory features about sanatoria for the poor in this country are the difficulty in obtaining early cases and the difficulty of obtaining suitable environment and occupation for cases after they leave sanatoria. The subject, however, is much too large to discuss here.

Open-air Schools.—No movement of the last fifty years is more fraught with hygienic possibilities than open-air schools. If adults require abundance of fresh air, even more do children require it; and the vitiated air of the ordinary school is responsible for much debility, both mental and physical. We have already quoted various tables showing the impurity of the air of ordinary schools, but a few more facts and opinions quoted by Sir John Gorst may be given here. A few years ago Dr. Bayley, of Owens College, made an examination of the air of schools in Manchester and Salford. He found in every case that the air was "very oppressive, giving rise to headache," and in most cases "the odour in the class-rooms especially was simply unbearable." He also found as much as 14·5 parts in 10,000 of carbon dioxide, and in one case as many as 286 microbes per cubic foot. The Royal Commission on Physical Training in Scotland found "that even in large and well-constructed rooms, the atmosphere is allowed to get into a condition that must be detrimental to health, and this is much more marked where the schoolrooms are inadequate to the attendance, and where they are not provided with proper means of ventilation." Dr. Eichholz says: "I suffer a good deal from what I am compelled to encounter on my visits round the schools. I constantly begin my work in a class-room by opening the windows. I consider a draught of less importance than the constant inhalation of fetid, vitiated air. I have seldom come across any evils of ventilation in a school that could not be altered in five minutes. If the windows are not open you can open them; and the children can be cleared out of the room if necessary. The draught is not a real objection, but is often an excuse for tolerating irrespirable air." Finally Dr. Kerr declares "Practically all schools are defective in point of ventilation."

Even as in sanatoria so in open-air schools, Germany has led the way, and the great open-air school started at Charlottenburg in 1904 is an object-lesson to the whole world. This school is so well described by Sir John Gorst in a work of this series, "The Children of the Nation," that we need not do more here than quote a few paragraphs of his description. The school was designed as "a school for ailing and convalescent children, at which the pupils should receive special care for their bodily infirmities, and should, at the same time, go on with their education, so far as their health permitted." The scholars, about 120 in number, "were selected by the school doctors from the public elementary schools of the town, and were finally examined and admitted by Dr. Bendix, who had medical charge of the Forest School."

The children come by foot or by electric tram, according to their distance from the Forest School, and at eight o'clock, after a bowl of soup and a slice of bread-and-butter, begin lessons. The time is divided into half-hour lessons; after each half-hour there is a five minutes' rest, and after each hour a ten minutes' rest; and no instruction is continued longer than two hours at a time.

"At first," writes Sir John Gorst, "all the arrangements of the Forest School aroused the most varied objections on the part of the parents; it was difficult to persuade them to contribute the moderate cost of maintenance. But by degrees, as the children grew better and happier in the green woods, as the pale cheeks turned red, as the eyes became bright and the movements more lively and fresh, so confidence was developed among the parents—they listened in the evenings to the tales of their children, who seemed to bring a breath from the forest into the hot, close, city dwelling; and they began to visit the Forest School, to convince themselves, with their own eyes, of the benefits offered to their children." Visitors soon came from all parts, and "all went away praising the experiment of making sick children healthy and happy. In the merry, rosy-cheeked children jumping about upon the grass under the pine-trees, it was difficult to recognise the feeble, pale-faced patients brought up from the streets of Charlottenburg."

The improvement in the scholars after a few weeks residence was astonishing. "Their appetite was extraordinarily improved, their disposition became joyous and merry, their attention was lively, and the appearance of almost all thoroughly satisfactory."

The following is the report of Dr. Bendix:—

"1. *The Anæmic.*—Out of 42 children—24 girls and 18 boys—none had grown worse, 5 were unaltered, 19 had got better, and 18 were cured.

"2. *The Scrofulous.*—Out of 50 children—24 boys and 26 girls—none had grown worse, 6 were unaltered, 34 had got better, and 10 were cured.

"3. *Those suffering from Heart Affections.*—Out of 7 children—4 girls and 3 boys—none had grown worse, none were unaltered, but all had got better. In these diseases cure is out of the question.

"4. *Those with Lung Disease.*—Out of 12 children—4 girls and 8 boys—none had grown worse, 3 were unaltered, 9 had got better, and none were cured.

"The weight of almost all the children increased greatly during their residence at the Forest School. Of those who had remained during the whole time the school was open, the average increase of weight was 3·316 kilo each in 1904, and 3·825 in 1905. Even during the cold and rainy weather in October, notwithstanding some deficiency in shoes and stockings, none of the children caught cold or suffered from catarrh of the nose, or of the air-vessels of the lungs."

The educative results were equally remarkable.

"On the character of the children the Forest School exercised a favourable influence, especially in good order, cleanliness, and punctuality, as well as in consideration for one another. Life in the still wood, removed from all mischievous influences, the association with people of culture, the lively thankfulness for the good done to them—all this worked upon the children, so that they strove to show themselves worthy of the benefits received ; there was far less naughtiness in the latter than in the first weeks.

" A few weeks after the return, in 1904, of the first batch of the children to the ordinary schools, the school authorities inquired of the headmasters of three different schools, and received, without exception, favourable reports on the returned scholars—their greater freshness and keener interest in the lessons was again remarked."

As a result of two years' experience, Dr. Bendix recommends :—

" 1. That a greater number of sick children should be sent continuously year after year to the Forest School.

" 2. That the extension of the school buildings should be, in the first instance, directed to making it available in the winter months.

" 3. That the school should be enlarged so as to enable more children to be taken in."

And the Municipality of Charlottenburg is considering the desirability of making the school a boarding school as well as a day school.

Sir John Gorst writes : " What struck me most was the air of extraordinary joyfulness which pervaded the whole establishment, from the medical superintendent down to the smallest and poorest child, and I marvelled at the administrative ability which had, at so small a cost, provided such a great portion of health and happiness, to brighten at least the beginning of life to these poor children, so neglected in our country. It may justly be said to every sanitary authority in the United Kingdom 'Go and do thou likewise.' "

The sanitary authorities have already in some measure gone and done likewise. Already eight open-air schools have been opened in various parts of England.

The first open-air school in England was started in 1907 at the suggestion of Mrs. Bridges Adams. It was organised in Bostall Woods, on a site kindly lent by the Royal Woolwich Arsenal Co-operative Society. A hundred children suffering from heart and lung trouble, anæmia, and general debility were selected for treatment. The following is the report of the results of treatment—

"The School was open from July to October, and notwithstanding the wet season, the children worked, played, and had meals in the open air. All ordinary lessons were taken adapted to the surroundings. The experiment was a great success, and proved—

"(1) That certain diseases of eyes, throat, &c., can be cured by open-air treatment, while from the results obtained in so short a time in cases of weakness of lungs, heart, &c., there is no doubt that early treatment would enable the majority of cases to be cured.

"(2) That great improvement can be effected in the general condition of delicate children. The average increase of weight was between 6 and 7 lbs., while some of the worst cases when admitted, gained up to 10 and 12 lbs. Any one who saw the children upon admission and a week or two afterwards, could not fail to notice other signs of improved health, *e.g.*, the increased voice volume, power of movement, &c. Children who could scarcely walk at first were able to run, and eager to help in all kinds of tasks after a week or two, while one child who had been kept in a darkened room for many months, and was unable to bear the faintest ray of light, improved so rapidly that glasses were discarded, and she could read without pain before the school closed."

During the summer and autumn of 1908 seven more open-air schools were opened.

1. London County Council, Camberwell, Birley House.
2. London County Council, Woolwich, Shrewsbury House.
3. London County Council, Kentish Town, Montpelier House.
4. Halifax County Borough, Withens.
5. Halifax County Borough, Bermerside.
6. Bradford County Borough, Thackley.
7. Norwich County Borough, Belle Vue.

These schools, with the exception of the school at Withens, were conducted as day schools, and recognition was sought under the Elementary Education (Defective and Epileptic Children) Act, 1899. Under this Act the children must be selected as suitable cases by the medical officers of the authority, and must be taught in small classes and have short hours. Under this Act, too, the school curriculum must include manual training.

The number of children at the schools varied. The London schools took 90 children each; Bradford took 40, and Halifax, Bermerside, 65.

The manner of selection of children also varied. At Woolwich, no children suffering from heart disease were admitted. At Halifax most of the children were suffering from malnutrition, anæmia, and scrofulous glands.

By the courtesy of the Medical Department of the Board of Education we have been able to learn that the schools have worked satisfactorily, and that great improvement in the physical and mental condition of the children has resulted.

Of course, all these schools are merely tentative and experimental, and they are obviously deficient in various respects.

In the first place, they are merely day schools and summer schools. None of the schools opened earlier than June 10th, or remained open beyond October 31st. Now, if open-air schools are to be fully efficient they must be boarding schools, and they must be open all the year round. Fresh air is as essential to the health of children by night as by day, and in summer as in winter : indeed, it is probable that it is by night and in winter that foul air works most harm.

The experience of English sanatoria proves beyond doubt that open-air schools might be continued all the year round without danger, and with the greatest advantage to the children.

In the second place, it is probable that selection of children might be made on sounder economic principles. It is certain that *all* delicate and diseased children cannot at present be taught in open-air schools, and therefore it is requisite that those who are likeliest to respond best to open-air treatment should be selected, and such a criterion would naturally give preference to cases not of organic disease but of general debility, malnutrition, and anæmia.

In the third place, if the best results are to be obtained, open-air schools, like open-air sanatoria, must be under the personal supervision of resident medical officers. It is possible, indeed, that open-air schools could be most efficiently and economically conducted if run under the same management as sanatoria.

At first sight, the cost of any great system of open-air schools would seem to be prohibitive ; but health is always a good investment, and money spent in establishing the health of children will be much more than repaid by their increased working power and better health in adult life. The cost to the nation of ill-health in adult life is so great that no money can be wasted which is spent to prevent breakdowns in working years. It has been calculated that the *direct* cost of consumption alone to the ratepayers of England is over £2,000,000 per annum. Further, the cost would be much less than might at first sight appear, for open-air schools do not require to be palatial buildings with elaborate artificial systems of ventilation. A clean shed, an overhanging tree, are almost all that are required in the way of building; and a saving in the drug bill can be set against the cost of the food.

It may be mentioned that an Open-air Schools and Training Association has been started with the declared object of rousing public opinion to the danger of allowing a large portion of the population to drift into physical, mental, and moral inefficiency, and to help to provide a remedy:—

"1. By assisting in the establishing of open-air schools and settlements, where children may be trained for open-air life and work, and may so develop their own powers of initiative and resourcefulness as to become self-reliant and independent citizens, capable of bearing their share of the responsibility of the race.

"2. By acting as a bureau of information and a means of uniting all those interested and willing to help in the work.

"3. By providing lecturers who will go to any part of the country and explain the work and objects of the Association to any education authorities, societies, or groups of persons interested, by means of lectures, illustrated by lantern views, photographs, &c."

The address of the Hon. Secretary of the Association is 25, Wimpole Street, London, W.

The effect of open-air education in counteracting the moral and physical degeneracy consequent on city life can hardly be exaggerated. Those who have had charge of open-air sanatoria for the poor can testify that the open-air life not only improves the physical health of the invalid, but improves his morale in every way; and in the case of open-air schools, the chief moral danger of sanatoria—the danger of prolonged idleness—is absent.

In the case of poor children whose nights are often spent in foul air, and whose homes are hotbeds of disease, open-air education means a vigour and health of mind and body which they could never otherwise obtain. There has been of late years much talk of physical degeneracy, and people are beginning to recognise that the nation's best wealth is health; and nothing will so much improve the physique and health of the nation as open-air schools. The nation first to realise the importance of open-air education, and to develop in a large scale a system of open-air education, will outstrip all rivals in the race of life. There is reason to believe that nothing will so increase the happiness, the health, the moral and mental sanity of the nation as open-air schools.

INDEX OF NAMES

Acosta on mountain-sickness, 61
Aggazotti on altitude and the respiratory exchange, 59
Aitken, John, on distribution of dust, 163
  on dust the producer of rain, 163
  on thickness of fogs, 143
Anderson, *see* Carnelly
Andrewes, Dr. T. W., analysis of "Tube" air by, 180
Aristotle on respiration, 32
Arloing, experiments on the toxic nature of sweat by, 131
Armstrong on percentage of carbon dioxide in air, 22
Arrhenius on influence of carbon dioxide on temperature, 72
Aubin, *see* Muntz

Bayley, Dr., on the air of schools, 320
Beddoes, Dr., experiments on gas inhalation by, 262
Bendix, Dr., on the effects of open-air schools, 322
Benedicent, Dr. A., on influence of pressure on absorbed oxygen, 53
Beninde on tubercular dust, 187
Bergey, D. H., experiments on expired air, by, 128
Bert, Paul, on caisson-disease, 67, 68
Bert, Paul, on diminished pressure and the blood, 56
  and Jourdanet on mountain-sickness, 62
Beu on Sequard's "expired air" experiments, 127
Billings, J. S., experiments on expired air by, 128
  on vitiation *versus* draughts, 231
Binot, Dr. Jean, on germs at great altitudes, 176
Black, Joseph, carbon dioxide in air discovered by, 299
Blake, *see* Letts
Bodington, Dr. George, the open-air treatment originated by, 307
Bohr on the absorption of gases, 34
Borelli on air and the blood, 296
Boussingault, on adaptability of man to altitude, 56
  and Levy on percentage of carbon dioxide in air, 22, 23
Bowditch, Dr. H. I., on soil moisture, 98
Boyle, Hon. Robert, on the atmosphere, 1
  study of air by, 295
Brehmer, Dr. Hermann, open-air treatment of, 310
Breschet on a case of tight-lacing, 258

Broadbent, Sir William, on speaking as respiratory exercise, 256
Brodie on annual smoke abatement, 154
Brown and Escombe on carbon dioxide in air, 21
Browne, Sir James Crichton, on germs in settled dust, 179
Buchanan, Dr. G., on damp soil a cause of consumption, 98
Bunsen on atmospheric absorption of actinic light, 105
  on percentage of oxygen in air, 17

Caius, Dr., on coddling, 100
Campbell, Dr. Harry, on chest expansion with age, 250
  on chest measurement and vital capacity, 239
  on respiratory exercises, 254
Carnelly, Anderson, and Haldane on carbon dioxide in air, 192
  on germs in indoor air, 177
Carpenter, Dr., on sulphuric acid from coal consumption, 139
Catlin, George, on the value of nose-breathing, 252
Cavanagh, Dr. Francis, on infants' clothes, 259
  on walking exercise for the wind, 242
  on women's clothes, 260
Cavendish, preparation of nitrogen by, 301
Clayton on the velocity of wind, 14
Cleby on the lungs, 28
Coates, Dr. H., experiments on tubercle infection by, 189
Cohen, J. B., on fog and illness, 150
  on smoke deposits in Manchester, 137
  on smoke production in Leeds, 136
Cornet, experiments on tubercle infection by, 188, 189
Cornet on tubercular dust, 187
  on tubercular infection, 186
Coxwell, barometric experiments by, 4
Curie, Mme., discovery of radium by, 304

d'Arsonval, *see* Séquard
Dastre and Loye, experiments on expired air by, 126
Davis, Geo. E., on sulphuric acid from coal burning, 139
de Chaumont on carbon dioxide and bad smells, 130
  on carbon dioxide in air, 191
de Saussure on altitude and the nervous system, 59
  on carbon dioxide in air, 22
  on Mont Blanc, 56
de Varigny, Henry, on the molecules of the atmosphere, 2
  on carbon dioxide in the air, 20
Duclaux, E., on actinic light and the atmosphere, 106
Dyer, Sir W. Thistleton, calculation of fog deposit by, 136

Edwards, W. F., experiments on temperature and vitality by, 44
Ehrenberg on the distance travelled by dust, 161
Eichholz, Dr., on the air of schools, 320
Elster, researches in radio-activity by, 112
Escombe, *see* Brown
Evelyn, John, on evils of smoke, 152
  on manufacturers' smoke, 137

Fernet, oxygen and the blood, 37
Ferrel on direction of winds, 9
  on heat of various latitudes, 7
  on prevailing winds, 11
Firth, *see* Notter

Flack, Martin, oxygen inhalation experiment by, 270, 271
Fleck on ground air, 158
Flügge, experiment on germs exhaled in coughing by, 186
  on bacteria, 173
  on germs in sewage, 185
  on tubercular infection from sputum, 187
Formanek on decayed teeth and expired air, 131
Foster on respiration, 49, 294
Foster, Sir Clement le Neve, carbon monoxide poisoning described by, 156
Fox, C., on carbon dioxide in impure air, 114
Fränkel, B., observations of tubercle bacilli by, 188
Frankland, E., on the climate of Davos, 279
  on pressure and absorbed oxygen, 53
Frankland, Percy, on bacteria in London, 173
Friedlander, E. D., on dust particles, 164

GALEN on respiration, 32
Geitel, researches in radio-activity by, 112
Germano, Dr., on resistance of germs to drying, 184
Glaisher, barometric experiment by, 4
Gorst, Sir John, on the open-air school at Charlottenburg, 321, 324
Gott, Lewis, on the tornado, 13

HADLEY, George, on the direction of winds, 8
Haldane, E. S., on carbon dioxide in air, 21
Haldane, Dr. J. S., on body temperature, 93
Haldane, Dr. J. S., on carbon dioxide in air, 21
  on carbon monoxide in mines, 157
  on inspiration and germs, 185
  and Osborne, experiments on vitiated air by, 133
  —— on bad smells and carbon dioxide, 130
  —— on carbon dioxide in impure air, 116
  —— on germs in workrooms, 179
  —— on increase of carbon dioxide with air-space, 195
  —— on ventilation of factories, 192
  —— table of various gas-burners by, 121
  —— table on the rising of coal-gas products by, 122
  —— ventilation experiments by, 204, 207
  and Lorraine Smith, experiments on expired air by, 127
  see Carnelly
Hales, Stephen, on the composition of air, 299
Hall, Dr. J. G., on diseases of occupation, 166
Hance, Dr. I. H., experiment on tubercular dust by, 186
Hann, definition of climate by, 273
  on altitude and humidity, 88
Harries, H., experiments on volcanic dust and influenza by, 165
Harrington on vitiation *versus* draughts, 230, 231
Haughton, Dr., on latent heat in water vapour, 72
Helmholtz on friction and the velocity of wind, 14
Henshaw, N., experiments with air-pressure cures by, 262
  on respiration, 293
Hewlett, St. Clair T., on asepticity of the nostrils, 252

Heymann on voice-germs, 186
Hill, Prof. Leonard, on adaptability of man to altitude, 55
  on animal tissue-combustion under varying temperature, 44
  on forced breathing, 249
  oxygen inhalation experiments by, 268, 270
Hofmann-Wellenhof on poisonous matter in expired air, 126
Holder, H. E., on oxygen inhalation, 269
Hooke, Robert, on air and the blood, 296
Huggard, Dr., classification of climate by, 275
  on Alpine climate, 281
  on altitude and the nervous system, 60
  on atmospheric weight, moisture, and temperature, 5
  on latent heat in water vapour, 72
  on quickened pulse-rate, 54
  on red blood corpuscles and altitude, 57
  on relative humidity, 82
  on the climate of Davos, 280
  on the climate of Egypt, 285
  on the taking-up power of air, 84
Humboldt, definition of climate by, 273
Hutchinson on deep breathing, 248

JAQUET, Prof., experiment on altitude and the blood by, 57
Jessen, *see* Lehman
Jourdanet, *see* Bert, Paul
Just, T. H., on oxygen inhalation, 268

KEITH, J., on the ventilation of the Houses of Parliament, 215, 216
Kelvin, Lord, on the molecules of the atmosphere, 2
Kenwood, Dr. H. R., *see* Parkes, Dr. L.
Kerr, Dr., on the ventilation of schools, 320
Koch on tubercular infection, 186, 187
Köppen on the velocity of wind, 14
Körösi on germs, 183
Kronecker, Prof., on mountain-sickness, 62
  on pulse-rate, 54, 55

LANGLEY, J. P., on the absorption of actinic light by air, 109
Laschtschenko on voice-germs, 186
Lavoisier, discovery of the composition of air by, 303
Lehmann, and Jessen, on the condensed fluid of expired air, 127
  see Zuntz
Leroy on bare feet for children, 100
Letts and Blake on carbon dioxide in air, 21, 22
Leuwenhock, discovery of germs by, 169
Levy, *see* Boussingault
Lindenau on the lungs, 28
Lodge, Sir Oliver, on electricity and air, 111
Loewy on altitude and the respiratory exchange, 59
  on mountain-sickness, 63
Lortet on the pulse-rate, 54
Lower, Richard, on air and the blood, 296
Loye, *see* Dastre
Lubbert and Peters, experiments on expired air by, 127
Lunt, *see* Macfadyen

MACCORMAC, Dr. Henry, apostle of open-air treatment, 308
  on pure bedroom air, 238
Macfadyen, Dr., and Lunt on dust particles, 164

Mandl, method of teaching singing of, 256
Märker and Schultze on ventilation of stables, 202
Maxwell, Clerk, on the molecules of the atmosphere, 2
Maxwell, W. H., on Key's ventilation method, 217
  on open windows, 234
  on ventilation, 213
Mayou, John, on air and respiration, 296
  theory of breathing of, 298
Melander, Prof., on dust particles, 164
Mendeléef on the weight of the atmosphere, 3
Merkel on the toxicity of expired air, 127
Mermod on altitude and the respiratory exchange, 59
Miguel, Pierre, on bacteria in Paris, 171
Milroy, Dr. Gavin, on damp soil a cause of consumption, 98
Mitchell, S. W., experiments on expired air by, 128
Moore on mist, 89
Mosso on air circulation, 198
  on Alpine climates, 282
  on altitude and the nervous system, 60
  on an electrical storm, 111
  on mountain-sickness, 62, 63
Müntz, experiment on altitude and the blood by, 58
Müntz and Aubin on carbon dioxide in the air, 20, 22, 23

Neisser on the lightness of germs, 184
Newman, Dr. George, "Bacteriology and Public Health," by, quoted, 180
  on carbon dioxide in impure air, 116
Newman, Dr. George, on germs in underground bakehouses, 181
Newsholme, Dr. A., on sanatoria, 319
  on tubercle infection, 188
Newton, Prof., on meteorites, 162
Notter and Firth, on chimney ventilation, 207
  on mechanical ventilation, 229
  on sulphur in coal gas, 118
  on the effects of carbonaceous illuminants, 119
  on ventilation by aspiration, 208
Nowak, *see* Seegen

Oertel, Prof., on compressed air for catarrh, 265
Oliver, Prof., on diseases of occupation, 166, 168
Osborne, *see* Haldane, Dr. J. S.

Parkes, Dr. Louis, on circulatory air for ventilation, 200
  and Kenwood, Dr. H. R., on chimney ventilation, 207
  —— on propelled air, 215
  —— on the influence of effluvia on the olfactory nerves, 130
  —— on the necessity of mechanical ventilation, 230
  —— on the principles of ventilation, 224
  —— table of requisite air-space per head by, 194
Pascal, barometric discovery of, 4
Pasteur, early experiments on bacteria by, 171
  on fermentation by germs, 169
  on germs, 178
Pembrey, Dr. M. S., on soldiers' clothes, 260
  on wind as an intensifier of cold, 75
Perrier, barometric experiment by, 4
Peters, *see* Lubbert

Pettenkofer on carbon dioxide in air, 114, 191
  on ventilation, 200, 202
Priestley, the discovery of oxygen by, 301
Primrose on Glasgow's smoke production, 136
Ptolemy, Claudius, division of climate by, 273
Putnam, J. P., on ventilation, 202

Ramsay, Sir William, discovery of argon by, 303
  discovery of helium and other atmospheric gases by, 304
  on Mayou's theory of the atmosphere, 298
  on Rutherford's discovery of nitrogen, 300
Rauer, experiments on expired air by, 127
Raye, Prof., on the strength of the Cuban cyclone, 6
Rayleigh, Lord, discovery of argon by, 303
Regnard, Paul, experiment on absorption of oxygen pressures by, 58
Regnault on oxygen in air, 16
Reid, experiment on ventilation and appetite by, 316
Rey, Jean, and the combination of air and solids, 294
Richards, M. G. H., on carbon dioxide in impure air, 114
Richardson, Sir B. W., plan for smoke consumption by, 155
  on tight corsets and waistbelts, 258
Rideal, Dr. S., on carbon dioxide in air, 118
Robertson on the influence of altitude on the nervous system, 60
Roscoe on atmospheric absorption of actinic light, 105
Rubner on air dryness and water output, 97
  on loss of body heat by evaporation, 92, 94
Ruskin on smoke, 136
Russell, Hon. Rollo, on London fogs, 143
  —— effects of, on health, 148
  —— financial loss from, 147
Rutherford, Dr. Daniel, discovery of nitrogen by, 300

Saaka, Dr., researches in radioactivity by, 113
Salton, Douglas, on plenum ventilation, 215
Scheele, the discovery of oxygen by, 301
Schroeder, anticipation of the discovery of germs by, 169
Schulze, F., on percentage of carbon dioxide in air, 21, 23
  see Märker
Scott on the velocity of winds, 14
Sebelien, Prof. J., on actinic light, 105
Seegen and Nowak on poisonous matter in expired air, 126
Séquard, Brown, and d'Arsonval, on poisonous matter in expired air, 126, 127
  on toxicity of expired air, 127
Shaw, Dr. W. N., on London's smoke production, 136
Sivierato, Dr., experiments on expired air by, 127
Smith, E., on human discharge of carbon dioxide, 42
Smith, Graham, on germs at altitudes, 176
Smith, Lorraine, *see* Haldane
Smith, R. Angus, analysis of smoke by, 135
  on air pollution by albuminoid ammonia, 141
  —— by sulphuric acid, 140

Smith, R. Angus, on carbon dioxide in air, 20, 115
  on oxygen in air, 17
Spence, Peter, suggestion for smoke consumption by, 155
Sprung on the velocity of wind, 14
Strauss on bacteria in inspired and expired air, 185, 251
Suter, Dr. F., experiment on the influence of altitude on the blood by, 57
Sutton, Dr. Harvey, on heat apoplexy, 93
Sylvius on air and the blood, 296

TATHAM, Dr., on dangerous trades, 167
Taylor on sea air and tuberculosis, 288
Tebb, Dr. Scott, on carbon dioxide in impure air, 116
  on germs in tube railways, 180
Thomson, St. Clair, on microbes in London, 131
Thorpe on carbon dioxide in air, 21
Truchot on carbon dioxide in air, 22
Tschudi on mountain-sickness, 63
Tyndall, early experiments on bacteria by, 171
  on fermentation by germs, 169
  on germs, 170
  on pressure and absorbed oxygen, 53

VAN DE WAALS on the molecules of the atmosphere, 2
Van Helmont, discovery of carbon dioxide by, 294
Vernon, Dr., oxygen inhalation experiment by, 272
Viault on diminished pressure and the blood, 56
von Buch, Leopold, on the west wind at Tenerife, 11
von Fodor and Wollny on carbon dioxide in the air, 22

WALLACE, A. Russell, on the smoke nuisance, 155
Walther, Dr. Otto, the open-air treatment of, 310
Weaver, R. E., on carbon dioxide in impure air, 114
Whitelegge, Dr., on the inadequacy of mechanical ventilation, 230
Whymper on colour effects of dust, 103
Wilson, Dr. W. S., on the ocean as a health resort, 287
Wolffhügel on carbon dioxide in the air, 22
Wollny, *see* von Fodor
Wood, observations on the pulse-rate by, 54
Woodbury, C. J. H., on artificial humidity, 223

ZUNTZ on altitude and the respiratory exchange, 59
  on the lungs, 28
  and Lehmann on equine discharge of carbon dioxide, 42

SUBJECT INDEX

ACTINIC rays, absorption of, 105
  properties of, 108
  value of, in different places, 107
Aero-therapeutics, 262
Age, influence of, on the respiratory exchange, 47
Air, a mechanical mixture, 15
  amount required per head, 199
  and electricity, 110
  and radio-activity, 112
  and solar radiation, 102
  artificial humidity of, 223
  Boyle's theory of the composition of, 295
  change of, effects of, 290
  chemical composition of, 15
  circulation of, necessity of, 198
  climatic qualities of, 87
  compressed, *see* Compressed air
  damp, influence of, on health, 98
  discovery of carbon dioxide in, 299
  dry, effects of, 96
  expired, absence of germs in, 185
  —— influence of decayed teeth on, 131
  —— low value of the experiments on, 129
  —— percentage of carbon dioxide in, 33
  —— oxygen in, 33
  —— the condensed fluid of, 127
  —— the question of poisonous matter in, 126
Air, expired toxicity of, 127
  extreme dryness of, 223
  filtration of, 224
  for consumptives, 311
  fresh, curative effects of, 134
  ground, 158
  impure, 114
  inspired, percentage of carbon dioxide in, 33
  —— oxygen in, 33
  marsh, 159
  Mayou's theory of, 296
  medicated, the use of, 266
  night, fallacy concerning, 134
  —— purity of, 134, 238
  open, *see* Open-air
  polluted, 135
  residual, 31, 38
  school, *see* Schools
  sewer, 159
  space per head, table of requisite, 194
  stationary, 31
  still, absence of germs in, 178
  the, drying capacity of, 96
  tidal, 31
  vitiated effects of, 125
  —— —— reasons of, 128
  —— by carbon dioxide from illuminants, 117
  —— by carbon dioxide, respired, 122
  —— by waste products of the skin, 123
  volume of, at one inspiration, 31

Argand gas-burner, the, 120, 121
Alpine climate, *see* Climate, Alpine
Altitude, influence of, on humidity, 88
  see also Pressure, diminished
Alveoli of the lungs, 28
Ammonia, albuminoid, air polluted by, 141
  —— composition of, 141
  atmospheric, 15, 24
Anæmia, 37
  effect of open air on, 322
Anæsthetics, danger of cold when under, 45
Animals, influence of altitude on, 55
  relative respiratory exchange of, according to size, 46
Anti-trade winds, 8
Appetite, influence of ventilation on, 316
Aqueous vapour, *see* Water vapour
Argon, 24
  discovery of, 303
  percentage of, in air, 15
Arsenical vapours, poisonous effects of, 151
Aspiration, ventilation by, 208
  mechanical assistance of, 211
Assimilation by plants, 25
Atmosphere, the dynamical properties of, 2
  humidity of, 5
  molecules of the, speed of, 2
  movements of, 6
  pressure of, 2
  properties of, 2
  relation between pressure and moisture of, 5
  relation between pressure and temperature of, 6
  temperature of, 4
  weight of, 3
Atmospheres, artificial, 262
Atmospheric movement, 6
Atmospheric pressure, *see* Pressure, atmospheric
Austerlitz prisoners, death of, from vitiated air, 123

BACTERIA, *see* Germs
Barometer, height of, at various altitudes, 3
Bedrooms, artisans', germs in, 176, 177
Belfast, phthisis among linen-workers in, 169
"Black Hole of Calcutta," the, 131
Blackman air-propeller ventilator, the, 214
Blood, arterial, percentage of carbon dioxide in, 33
  —— —— oxygen in, 33
Blood, the, absorptive power of, 34
  chemical combination of, with oxygen, 37
  influence of diminished pressure on, 56
  regulation of respiration by, 48
  venous, percentage of carbon dioxide in, 33
  —— —— oxygen in, 33
Blood-cells, carrying function of the, 38
Boyle valves, 210
Breath, *see* Air, expired
Breathing, deep, danger of, 246
  —— uses of, 248, 249, 251
  diaphragmatic, the uses of, 257
  exercises, fallacies concerning, 244, 247
  —— good, 254
  —— the aim of, 248
  forced, value of, 249
  in tuberculosis, 255
  influence of corsets on, 257
  Mayou's theory of, 297
  position when, 256
  relation of, to circulation, 249
  through the nose, value of, 251

Breathlessness, speaking a cure for, 256

CAISSON-DISEASE, 67
Candles, *see* Carbonaceous illuminants
Carbon dioxide, coefficient of absorption of, for blood, 34
—— for water, 34
formation of, by decomposition, 41
in air, 15, 20
—— amount of, permissible, 191
—— discovery of, 299
—— method of accumulation, 194
in arterial blood, 33, 39
in expired air, 33
in impure air, 114
in inspired air, 33
in London air, 146
in venous blood, 33
influence of temperature on the output of, 44, 45
maintenance of right percentage of, 193
on the Metropolitan Railway, 117
production and properties of, 19
relation of, to bad smells, 130
relative animal discharge of, 41
relative human discharge of, 42
respired, vitiation of air by, 122
transference of, from blood to air, 36
Carbon monoxide, coefficient of absorption of, for water, 34
poisoning, 37
production of, 117
properties of, 156
red-hot iron pervious to, 221
Carbonaceous illuminants, influence of, on the atmosphere, 119
Carburetted hydrogen in air, 24
"Change of air," effects of, 290
Charlottenburg, open-air school at, 321
Chest, expansion, fallacy concerning, 240
—— mechanism of, 29
—— with age, 250
—— influence of gymnastics on the, 242
measurement and vital capacity, 239
—— big, fallacy concerning, 239, 250
muscles, the, danger of exercise to, 243
shape of the, 241
Children, effect of tight clothing on, 259
influence of fresh air on, 322
"Chills," 232
Circulation, of air, *see* Air, circulation of
relation of, to breathing, 249
thermal, 201
Climate, classification of, 275
definition of, 273
desert, character of, 283
high Alpine, 278
—— causes of the value of, 281
—— curative effects of, 282
of Egypt, 285
of South Africa, 284
sea, 286
therapeutical selection of, 278
Clothes, importance of looseness of, 261
uses of, 90
women's, 260
Clouds, 88
Coal, carbon dioxide from the use of, 116
origin of, 26
Coal gas, carbon dioxide from the use of, 118
composition of, 118
the source of atmospheric sulphur, 118

Coal miners and consumption, 167
Coddling, the evils of, 99
Cold, perflation the cure for, 235
  stuffiness the cause of, 235
  see Temperature, low
Compressed-air, baths, uses and properties of, 264
  for catarrhal inflammation, 265
  for consumption, 266
  medical use of, 264
  see Pressure, atmospheric, increased
Conduction, influence of humidity on, 91
  loss of body heat by, 91
Consumption, *see* Tuberculosis
Corsets, effect of, on breathing, 257
Cowls, value of, for ventilation, 211
Crying, babies', good respiratory exercise, 257
Cyclones, 13

DAMP, dangers of, exaggerated, 100
  feet, fallacy about, 100
  influence of, on consumptives, 314
  —— on germs, 101
  sheets, 101
Dampness, relation of, to rainfall, 89
Davos, the climate of, 279
Dew, 89
Dew-point, the, calculation of, 79
Diaphragm, the, strength of, 257
Diarrhœa, epidemic, and air infection, 190
Diet, influence of, on the respiratory exchange, 46
Diffusion, ventilation by, 201
Diseases of occupation, 166
Drill, damage to soldiers from, 242
Dust, artificial, harmful effects of, 166
  colour effects of, 103
  composition of, 162
  diseases from the inhalation of, 166
  functions of, 161
  organic, 169
    problem, the, solution of, 190
  rain produced by, 163
  raised by motor cars, 190
  source of, 161
  tubercular, danger of, 187
  value of, for distributing light, 102
Dusting—redistribution of germs, 183
Dusts, vegetable, dangers of, 169
Draughts, big, the slight dangers of, 234
  cause of, 12
  small, the dangers of, 233
  the fear of, 231
  versus vitiation of air, 230, 231

EFFLUVIA, influence of, on the olfactory nerves, 130
  organic, the nature of, 130
  relation of, to carbon dioxide, 130
Egypt as a health resort, 284
Electric potential, increase of, with altitude, 111
Electrical storm, description of an, 111
Electricity, and air, 110
Ellison's bricks, 208
Evaporation, influence of humidity on, 91
  loss of body heat by, 91, 94
Exercise for consumptives, 318
Expiration, forced, 31
Expired air, *see* Air, expired

Factories, recommendations for the ventilation of, 192
Fans, ventilating, 214
Feet, bare, children and, 100
  damp, 100
Fires, gas, for heating, 221
  open, for heating, 221
"Flue," 169
Fog, cause and nature of, 142
  city, 143
  colour of, 144
  deposit of unburnt carbon by, 136
  dry, 144
  effects of, on the health, 147, 150
  experimental, 143
  financial aspects of, 145
  legislation against, 151
  London, calculation of financial loss by, 147
  suffocation of animals by, 149
Food, abstinence from, in hot weather, 94
  and oxygen, 315
  for consumptives, 314
Furnaces, for heating, 221

Ganister miners, mortality among, 168
Gas, *see* Coal-gas
Gas-burners, table of, 121
Gases, mixed, behaviour of, under pressure, 35
  solubility of, 34
Germs, absence of, in expired air, 185
  —— in uninhabited regions, 170
  at different altitudes, 175
  conveyance of, 182
  damp a developer of, 101
  ejection of, by the voice, coughing, &c., 185, 188
  fewness of, in summer, 173
Germs, from sewage, 185
  in churches, 184
  in dirty houses, 183
  in Lille, 181
  in London, 173, 174, 181
  in middle-class houses, 183
  in mills, 178
  in New York, 181
  in Nottingham, 181
  in organic dust, 169
  in Paris, 172
  in public buildings, 184
  in railway air, 181, 182
  in stable-yards, 182
  in still air, 178
  in theatres, 184
  in tube railways, 180
  in underground bakehouses, 181
  in workrooms, 179
  indoor, 175, 177
  influence of cleanliness on, 179
  lightness of, 184
  nostrils destructive to, 252
  outdoors, 174
  number of, inspired, 131
  pathogenic, distribution of, 182
  resistance of, to drying, 184
  susceptibility of the body to, when cold, 95
  treatment of, after inspiration, 132
  universality of, 170
Glasgow, production of sulphuric acid from coal in, 145
Guibal's Fan ventilator, 214
Gunpowder blasting, effect of, on mine air, 158
Gymnastics, influence of, on the chest, 242

Hæmoglobin, chemical combination of, with oxygen, 37, 39
Heart, the, influence of diminished pressure upon, 55
  relationship of, to the respiratory mechanism, 50

Heart disease, effect of open-air on, 322
Heat apoplexy, cause of, 93
  latent, in water vapour, 72
  physiological effects of, 74
Heating, methods of, 220
Helium, discovery of, 304
  in air, 15, 24
Hinckes-Bird Ventilator, the, 209
Houses of Parliament, the, ventilation of, 213, 215, 216
Humidity, absolute, 77, 86
  —— high, effects of, 86
  artificial, 223
  influence of altitude on, 88
  —— on conduction, 91
  —— on evaporation, 91
  —— on radiation, 91
  —— on the body, 90
  relation of, to atmospheric pressure, 5
  relative, 77, 80
  —— at different times and places, 83
Hydrocarbons, absorption of heat by, 73
Hydrochloric acid, in smoke, regulations as to, 154
  influence of, on health and vegetation, 151
Hydrogen, atmospheric, 15, 24
  in the air of mines, 158
  peroxide in air, 15
Hygrometrical Tables, Glaisher's, the use of, 79, 80

INDOOR living, bad effects of, 99
Infants, effect of tight clothing on, 259
Infundibula, structure of, 28
Inhalations, medical, 262

KEY'S ventilation method, 217
Kite's air propeller, 214
Krypton in air, 15, 24
  discovery of, 304

LEAD-POISONING from lead-dust, 168
Light, *see* Sunlight
Lockjaw, bacillus of, found in stable-yards, 182
Lodging-houses, ventilation of, 200
London air, carbon dioxide in, 146
  percentage of chemical impurities in, 141
  regulations as to smoke in, 153
Londonderry, steamer, death of passengers from vitiated air, 124
Lungs, the, mucous surface of, 28
  structure of, 28

MCKINNELL'S ventilator, 210
Malaria, erroneous interpretation of, 134, 232
Manchester, influence of fog on sickness in, 150
  production of sulphurous acid in, 146
  smoke deposits in, 137
  stoves, for heating, 221
Marsh gas, atmospheric, 24
  in mines, 157
Methane, *see* Marsh gas
Microbes, *see* Germs
Mills, germs in, 178
Miners, consumption among, 167
Mines, marsh gas in, 157
  the air of, 156
  ventilation of, 212
Mist, 89
Moisture, effect of, on ventilation, 222
Monsoons, the, 12
Mountain-sickness, Acosta's description of, 61
  theories of the cause of, 62

Moustache, the, danger of, in tuberculous cases, 187
Mucus, 29
Muller's experiment, 254
Muscular activity, influence of, on respiration, 41

NEIL Arnott's valves, 210
Neon, discovery of, 304
  in air, 15, 24
Nerves, the respiratory, 30
  the, regulation of respiration by, 48
Nervous system, the, influence of diminished pressure on, 59
Nitric acid, atmospheric, 24
Nitrogen, atmospheric, 24
  coefficient of absorption of, for blood, 34
  coefficient of absorption of, for water, 34
  discovery of, 300
  percentage of, in air, 15
Nitrous acid, atmospheric, 24
Nostrils, the, functions of, 251
  germ-destroying power of, 252

OIL, *see* Carbonaceous illuminants
Open-air, school, *see* Schools, open-air
  treatment, of consumption, 305
  —— the earliest, 306
Open windows, *see* Windows, open
Overcrowding, and tuberculosis, 306
Oxygen, absorption of, effects of diminished pressure on, 53
  and food, 315
  coefficient of absorption of, for blood, 34
  coefficient of absorption of, for water, 34
  combination of, with fat, 41
Oxygen, combination of, with hæmoglobin, 37
  deficiency of, in towns, 17
  discovery of, 301
  in air, 15, 16
  in arterial blood, 33
  in expired air, 33
  in inspired air, 33
  in Metropolitan Railway air, 117
  in venous blood, 33
  inhalation of, and holding the breath, 272
  —— by horses, 270
  —— effect of, on athletes, 268
  —— for swimmers, 270, 271
  —— value of, 267
  lowered percentage of, effects of, 17
  properties of, 16
  transference of, from air to blood, 36
Ozone, absorption of heat by, 73
  formation and properties of, 18
  in air, percentage of, 19

PERFLATION, and draughts, 228
  by open windows, 231
  the essence of ventilation, 237
  ventilation by, 207
  ventilatory, assistance of, 211
Perspiration, *see* Sweat
Pipes, hot water and steam, for heating, 222
Plants, influence of altitude upon, 55
Plenum ventilation, 214
"Ponce," 169
Position, of the body, importance of, 256
Pott's ventilator, 211
Potter's rot, 168
Pressure, atmospheric, diminished, effects of, 52

Pressure, atmospheric, diminished, effects of, on the blood, 56
—— —— —— on the nervous system, 59
—— —— —— on the pulse-rate, 53
—— increased, influence of, 63
—— mechanical effects, of, 64
—— influence of, on the taking up of oxygen, 39
modification, apparatus for, 263
Pulse-rate, the, as indicator of altitude, 54
influence of diminished pressure on, 54

Radiation, influence of humidity on, 91
loss of body heat by, 90
Radio-activity, and air, 112
Radium, discovery of, 304
Rain, produced by dust, 163
Rainfall, 89
at different times and places, 83
Respiration, ancient theories of, 293
Mayou's theory of, 296
meaning of, 32
of animals, 27
of fishes, 27
of plants, 26
of the lower organisms, 26
of water insects, 27
process of, 25
regulation of, 47
Respiratory capacity, 31
centre, the, 49
exchange, the, influence of altitude on, 59
mechanism, the, reflex adaptability of, 49
—— the, relationship of, to the heart, 50
Respiratory organs, the, of man, 27
Root's Blower ventilator, 214

Sanatoria for the poor, 319
origin of, 310
Scent, the, of flowers, possible functions of, 73
Scents, absorption of heat by, 73
Schools, germs in the air of, 177
open-air, 319
—— effects of, on disease, 322
the air of, 320
Scrofula, effects of open-air on, 322
Sea, the, climate of, 286
Sea-voyages, medical uses of, 289
Sewage, danger of germs from, 185
Sheffield, regulations as to smoke in, 153
Sheringham valve ventilator, the 209
Short-windedness, cause of, 50
Singing as a respiratory exercise, 256
Skin, the, adaptability of, to the air, 237
products of, given to the air, 123
variety of odours emanating from, 130
Sleep, danger of cold during, 45
Smells, bad, *see* Effluvia
Smoke, 135
annual abatement of, 154
consumption, suggestion for, 155
deposits, analysis of, 137
effects of, on health, 147
legislation against, 151
production of, in Glasgow, 136
—— in Leeds, 136
—— in London, 136
regulations as to, in various towns, 153
social evil of, 138
solid constituents of, 136

Smokeless fire, inventions to obtain a, 154
Snow, influence of, on percentage of carbon dioxide in air, 23
Soil moisture, the law of, 98
Soldiers, the clothing of, 260
Spring-cleaning, and germs, 184
Stevens' drawer ventilator, the, 209
Stonemasons' phthisis, 168
Sturtevant Blower ventilator, the, 214
Stoves for heating, 221
Subsoils, influence of, on health, 97
Sulphur, production of, by coal gas, 118
Sulphuretted hydrogen, in the air, 24
  —— of mines, 158
  poisonous effects of, 151
Sulphuric acid, pollution of the air by, in various places, 140
  production of, by coal burning 139, 145
Sulphurous acid, production of, by coal consumption, 145
  in Manchester, 146
Sun, the, influence of, on health, 109
  the cause of the winds, 7
Sunlight, analysis of, 103
Surface, body, influence of, on the respiratory exchange, 46
Sweat, constituents of, 123
  experiment on the toxic nature of, 131
Sweeping—redistribution of germs, 183
Sylvester ventilation method, the, 211

TEETH, decayed, influence of, on expired air, 131
Temperature at different times and places, 83
Temperature, body, constancy of, 69
  —— influence of heat and humidity on, 93
  external, influence of, on respiration, 43
  indoor, 222
  influence of carbon dioxide on, 72
  —— terrestrial radiation on, 73
  —— vegetation on, 74
  —— water vapour on, 72
  low, influence of, on the body, 94
  relation of, to atmospheric pressure, 4
Thermometer, the wet and dry bulb, use of, 79
Tin-miners, mortality among, 168
Tobin's tube ventilator, 209
Tornadoes, 13
Towns, excess of carbon dioxide in, 23
Trachea, the, structure of, 27
Trade winds, the, 8
Trades, dangerous, 167
  offensive gases from, 159
"Training," the value of, 42
Tube railways, germs in, 180
Tuberculosis, air infection in, 186
  breathing in, 255
  coal-miners and, 167
  compressed-air treatment of, 266
  dampness of soil as a cause of, 98
  danger of sea-voyages in, 289
  effect of desert climate on, 284
  —— sea-air on, 288
  in Australian mines, 167
  infection of, from dried sputum, 186
  —— from the moustaches, 187
  on the Rand, 167
  open-air treatment of, 310
  relation of, to overcrowding, 306
Tuberculous spray, 187

VALSALVA's experiment, 254
Vapour, *see* Water vapour
Vegetation, influence of, on percentage of carbon dioxide in air, 22
—— on temperature, 74
Ventilation, 191
  and tuberculosis, 306
  artificial, 212
  by aspiration, 208
  by chimneys, 207
  by diffusion, 201
  by fans, 214
  by heat, 212
  by perflation, 207
  by steam-jet, 213
  by water spray, 214
  by windows, 209
  effect of moisture on, 222
  efficiency of, testing the, 224
  influence of damp on, 206, 207
  —— on appetite, 316
  —— on health, 226
  inlets, 225
  Key's method of, 217
  mechanical, inadequacy of, 229
  natural, 201
  of low-class houses, 228
  of schools, 320
  of the Houses of Parliament, 213, 215, 216
  outlets, 210, 225
  plenum, 214
  spontaneous, 202
  thermal, 201
  upward *versus* downward, 218
  vacuum, 212, 214
  versus draughts, 230, 231
Ventilators, artificial, patented, 208

WAIST-BELT, tight, evils of the, 258
Water, importance of, to the body, 95, 97
  loss of, from the body per day, 95
  output, influence of dryness of air on, 97
  vapour, a regulator of temperature, 72
  —— capacity of air for, 76
  —— in air, calculation of, 77
  —— in expired air, 40
  —— latent heat in, 72
  —— table of tensions of, 81
Welsbach gas-burner, best form of gas light, 120
  description of, 120
Widnes, production of the sulphur acids from coal consumption in, 139, 145
Wind, the, exercises for, 242
  an intensifier of cold, 75
  influence of, on percentage of carbon dioxide in air, 23
  rate of, 13
  vaso-motor effect of, 313
Windows, open, prejudice against, 231
  —— theory of, 312
  —— value of, 234, 236, 237
Winds, the, causes of, 6
  direction of, 8
  trade and anti-trade, 8

XENON, discovery of, 304
  in air, 15, 24

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Handbooks of English Church History	14
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"Home Life" Series	14
Illustrated Pocket Library of Plain and Coloured Books	15
Leaders of Religion	15
Library of Devotion	16
Little Books on Art	16
Little Galleries	17
Little Guides	17
Little Library	18
Little Quarto Shakespeare	19
Miniature Library	19
New Library of Medicine	19
New Library of Music	19
Oxford Biographies	19
Three Plays	20
States of Italy	20
Westminster Commentaries	20
"Young" Series	20
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